ARMSTRONG LABORATORY

CREW ESCAPE TECHNOLOGIES (CREST) MISSION AREA REQUIREMENTS STUDY CURRENT AND FUTURE CREW ESCAPE REQUIREMENTS

North American Aircraft
Rockwell International Corporation
P.O. Box 92098
Los Angeles, CA 90009

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WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6573

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FOR THE COMMANDER

Thomas J. Moore

THOMAS J. MOORE, Chief
Biodynamics and Biocommunications Division
Crew Systems Directorate
Armstrong Laboratory

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The past twenty years of crew escape system's research and development has seen most of the development activity aimed at the third generation of ejection seats where performance requirements are stated MIL-S-9479B dated March 1971. The Crew Escape Technologies (CREST) advanced development program is concentrating on the technologies for the development of escape systems for aircraft of the year 2000 and beyond, such as the proposed Multi-Role Fighter. Approximately ten years ago the CREST program estimated requirements for a fourth generation ejection seat and began the technology development process. Part of this effort in a CREST Specifications document which contained a compilation of the estimated fourth generation seat requirements. A reassessment and update of these requirements was needed. The main objective of the CREST Mission Area Requirements Study was to provide an updated look into the operating environment and associated required performance of the next generation of ejection systems. Rockwell International's North American Aircraft Division teamed with Logistics Management Engineering Incorporated (LME) to organize and execute a technical approach to the CREST (continued)

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program. Four specific tasks were accomplished in the program. Task 1 - Third Generation Escape System Performance Comparative Analysis - was used to compile and compare performance capabilities of current third generation ejection seat systems. Task 2 - Performance Requirements of Future DOD Aircraft by Mission Type - compiled data on future DOD aircraft concepts and their anticipated performance capabilities. The concepts were based on these specified mission applications--trainers, close air support, air superiority, tactical and strategic bombing, special operations, and hypersonic reconnaissance and strike. Task 3 - Analysis of Third Generation Escape Systems to Meet Future Aircraft Escape Requirements - used the results of Tasks 1 and 2 to compare third generation seat performance to the predicted performance of the future aircraft concepts. This comparison identified performance deficiencies in the third generation seat systems. Finally, Task 4 - Analysis and Recommendations for Fourth Generation Escape System Performance Requirements - was used to review results from Tasks 1 through 3, and apply findings to the CREST Specifications document.
Results of the study identified that current third generation ejection seat systems and associated proposed improvements were inadequate for providing the performance necessary to meet the predicted performance of the future aircraft concepts. This was found especially true for fighter aircraft concepts capable of high speed and maneuverability. Moreover, it was found that the current CREST Specifications document was also inadequate in several areas for providing requirements which cover the anticipated performance and mission envelopes of the future aircraft concepts. Again, this was especially apparent for high speed and maneuverability, as well as near ground flight conditions such as terrain following. These results prompted specific change recommendations to the CREST Specifications document to better ensure that fourth generation seat systems adequately meet the performance goals of future DOD aircraft.

Foreword

This report was prepared under contract F33657-90-D-0030 call order 0007, Crew Escape Technologies (CREST) Mission Area Requirements Study. Sections 2.1, 2.3, and 2.4, and Appendices A through D of this report were provided by Logistics Management Engineering Company under Rockwell subcontract L1FM-703408-F. The period of performance for this effort was August 1991 through 29 February 1992.

Section 2.2 analysis and reporting was provided by Steven Cass, Rockwell International, North American Aircraft, Advanced Configuration Design Group. Sections 2.1, 2.3, and 2.4, and Appendices A through D were provided by Walter Peck and James Duncan of Logistics Management Engineering Company. Appenix E was provided by H. G. Casteel, Rockwell International, in addition to major technical guidance and support.

The Program Manager for this effort was W. J. Adams of North American Aircraft.

The Project Engineer for this effort was R. E. Zegler of North American Aircraft, Hypersonic Programs.

The government technical monitor for this effort was Cpt. B. Badami, CREST Program Manager, AL/CFA-CREST ADPO.

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Executive Summary

The past twenty years of crew escape system's research and development has seen most of the development activity aimed at the third generation of ejection seats where performance requirements are stated in MIL-S-9479B dated March 1971. The Crew Escape Technologies (CREST) advanced development program is concentrating on defining escape system technologies necessary for implementation into aircraft of the year 2000 and beyond, such as the proposed Multi-Role Fighter. Approximately ten years ago the CREST program estimated requirements for a fourth generation ejection seat and began the technology development process. Today, a reassessment of the requirements for a fourth generation ejection is needed. The capabilities of the existing third generation seats and their planned improvements is also needed along with an analysis of future aircraft requirements. The fourth generation ejection seat requirements need to be analyzed against future aircraft requirements and either reaffirmed or modified.

The main objective of the CREST Mission Area Requirements Study was to provide an updated look into the operating environment and associated required performance of the next generation of ejection systems. The study compiled performance data for current third generation ejection systems, and their proposed follow on improvements, for comparison to the anticipated performance of future DoD aircraft (year 2000 and beyond). The comparisons were used to identify specific areas where ejection systems had performance deficiencies relative to the anticipated performance of the future aircraft concepts. With these deficiencies outlined, ejection system design performance specifications including the CREST Systems Specification for fourth generation ejection seat development were reviewed, and specific change recommendations were made to ensure that fourth generation seat concepts incorporate the performance goals necessary to meet future DoD aircraft capabilities, and improve ejection survivability.

Rockwell teamed with Logistics Management Engineering Company (LME) to organize and execute the technical approach to the CREST program. Four specific tasks were outlined within the technical approach. Task 1 - Third Generation Escape System Performance Comparative Analysis - was used to compile and compare performance capabilities of current third generation ejection seat systems. Task 2 - Performance Requirements of Future DoD Aircraft by Mission Type - compiled data on future DoD aircraft concepts and their anticipated performance capabilities. The concepts were based on a specified set of mission applications. Task 3 - Analysis of Third Generation Escape Systems to Meet Future Aircraft Escape Requirements - used the results of Tasks 1 and 2 to compare third generation seat performance to the predicted performance of the future aircraft concepts. This comparison identified performance deficiencies in the third generation seat systems. Finally, Task 4 - Analysis and Recommendations for Fourth Generation Escape System Performance Requirements - was used to review results from Tasks 1 through 3, and apply findings to the CREST System Specification. This included making specific change recommendations to better ensure that fourth generation seat systems adequately meet the performance goals of future DoD aircraft. Results of the four tasks are further summarized below.

Task 1 performed a study on four ejection seat configurations typical of third generation escape systems. Performance trends of these seats were compared to the Air Force's Ejection Seat General Specification MIL-S-9479B dated 1971. The configurations evaluated were the ACES-II seat developed by the Douglas Aircraft Division of the McDonnell-Douglas Aircraft Corporation for the Air Force in the early 1970's; the unqualified ACES-II PLUS modification to the ACES-II seat recently completed by McDonnell-Douglas; the NACES seat developed by the Martin-Baker Company for the U.S. Navy and qualified under the MIL-S-18471G, Ejection Seat General Specification, and the unqualified S4S ejection seat developed by the Stencel Aero Engineering Corporation in the mid 1980's (which is a product upgrade of the SIIIS-3 configuration qualified by the NAVY under MIL-S-18471D.) [Although many differences in technical philosophy exist between the two service specifications, the overall objectives are relatively comparable.]

Prior to the comparative analysis an evaluation of subsystems that directly affect recovery performance of the escape system was conducted. This evaluation was based on the experience of LME personnel, and was essential to performing the comparative analyses of the third generation escape systems. The components considered in this evaluation included: restraint harnesses and powered inertia reel devices; propulsion subsystems; pitch/yaw stabilization subsystems; altitude/airspeed sensing subsystems; post ejection sequencers, and main recovery parachute subsystems.

The requirements of MIL-S-9479B for the performance of these subsystems were compared to the estimated performance of these subsystems in the S4S, the ACES-II and the NACES ejection seats based upon computer studies of shock wave effects, as well as upon the test data recorded in track and/or flight system tests. No test data was available for the ACES-II PLUS ejection seat and only very limited data was available for the S4S ejection seat.

Graphical comparisons were made of the total demonstrated performance of the three baseline ejection seats. These included the time required for the aerodynamic stabilization subsystems to become effective (drogue parachutes, or fins for the S4S), and the time required for the recovery parachute to reach "first full inflation" as a function of the airspeed at ejection. These comparisons are shown Figures ES1 and ES2. The time to catapult separation and/or booster rocket ignition was included to represent the approximate point where airspeed and altitude sensing begins, and in some cases, where time delays are selected and started. Although subject to interpretation by the data analyst, the time to "first full inflation" was considered to be the most significant parameter available for comparison. Other equally or more significant parameters such as times to final full inflation, vertical descent or terminal velocity are seldom, if ever, observable in ground level track tests which was the source of most of the data.

Comparisons of head and neck loading were also done for this effort. None of the third generation seats provided any type of head restraint or protection other than the headrest structure. However, due to differences in drag/mass ratios, loads applied to the head and neck were directly influenced by the individual ejection systems. One notable outcome of this comparison was the effect of the drogue parachute on each of the three systems. The comparison showed that before the drogue parachute became effective the net force on the head was aftward, pushing the head back against the headrest on all three systems. Examination of the equations and system parameters showed that the NACES caused higher aft head loads prior to drogue inflation mainly because its greater weight reduced the magnitude of the seat deceleration and the inertia force of the head. This allowed the dynamic pressure on the head to be predominant. The differences in the three systems became much more pronounced after their drogue parachute became effective. Figure ES3 summarizes results of the head loads comparison for this effort.

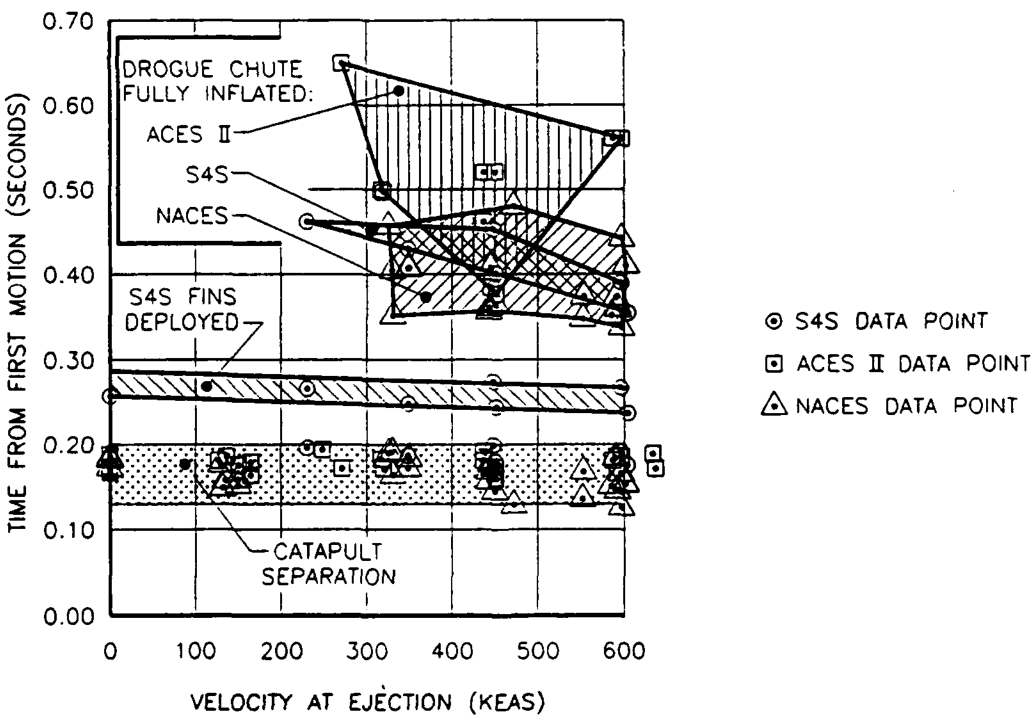
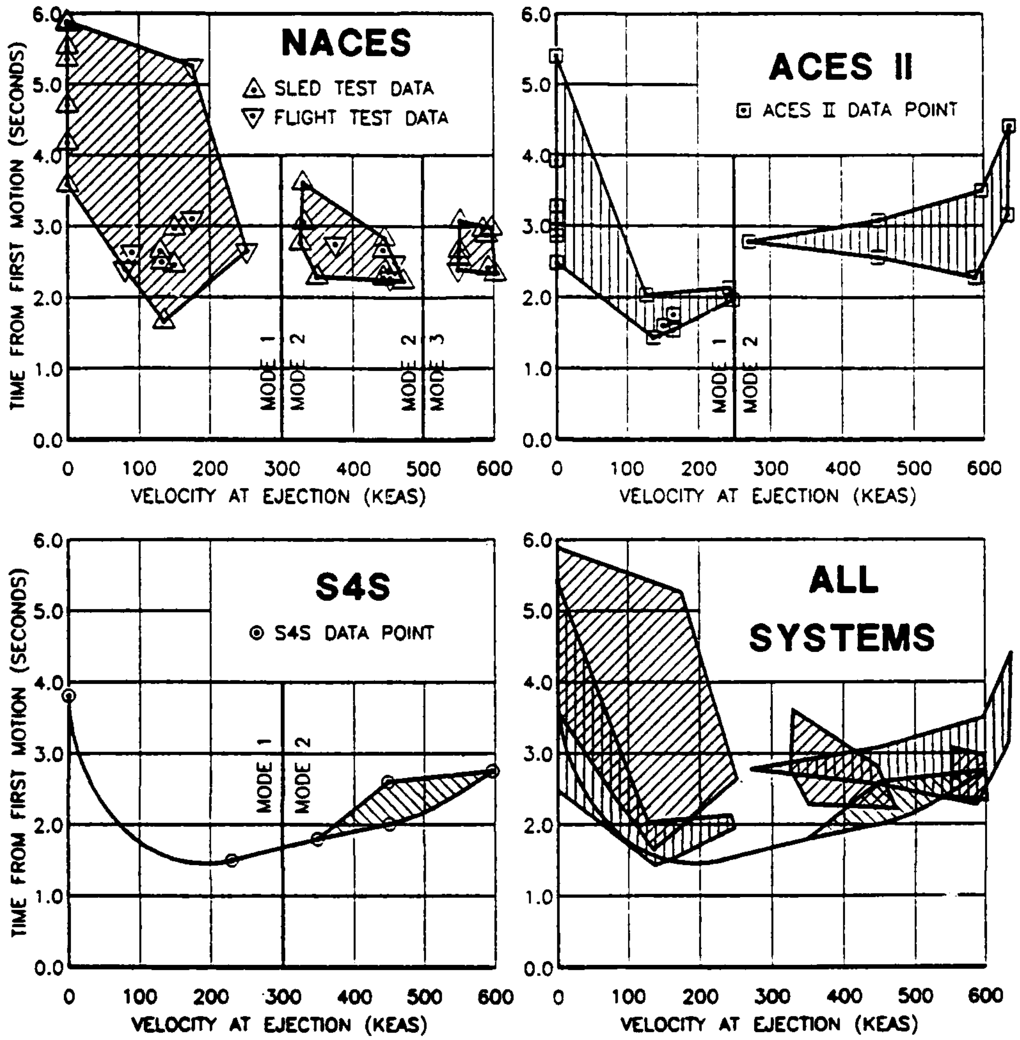


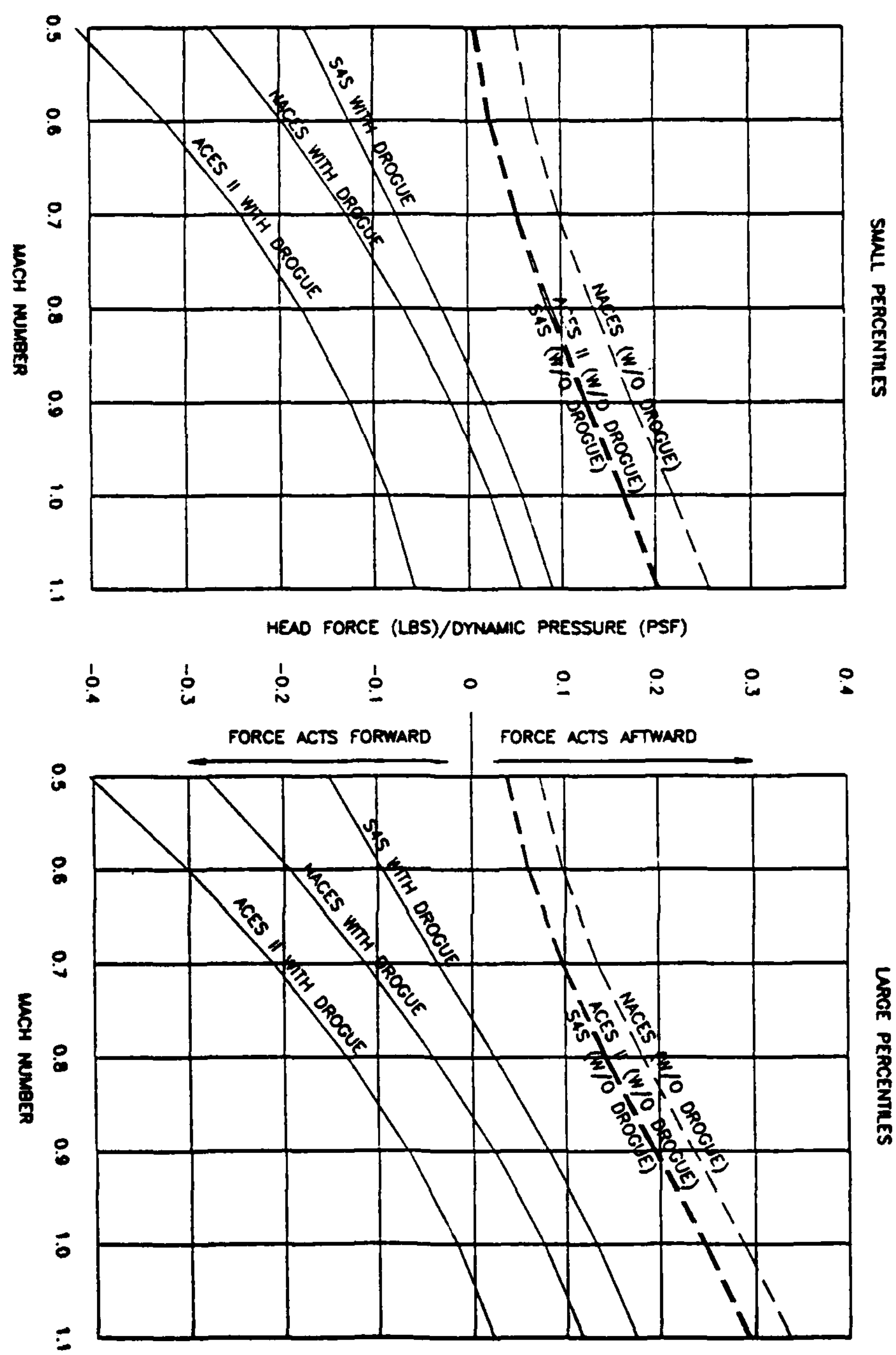
Figure ES1
Time to Drogue Inflation and Fin Deployment Demonstrated Performance



[*Velocity decay curves for the third generation seats studied were not available to LME. It is noted, however, that first full inflation (how ever it was determined) was included in all test report data provided to LME, and was the only data point relative to dummy recovery that was provided in all test report data. Also, based upon parachute testing experience, it is believed that even in high speed ejection tests a safe total velocity will be reached within 0.3 seconds after first full inflation has occurred in the parachutes which are used in the third generation ejection seats studied.*]

Figure ES2
Time to First Full Inflation Demonstrated Performance

The individual comparisons made in this task represent the basic conclusions for this effort. No additional attempts were made under this task to rate any one specific system or subsystem component over another (other than what was contained in the parameters of the comparison). The comparison data was used in Tasks 3 and 4 as the premise for examining the effectiveness of current ejection system technology to meet anticipated user needs in future application. More detailed conclusions regarding the relative ability of each of the ejection systems, and subsystem components, to meet these needs were formulated in the respective tasks.



[The neck tension data recorded in wind tunnel tests which was made available to LME for this study was not sufficiently consistent with itself to warrant presentation of the data. The neck shear loads are valuable in showing the problems which must be faced in a high G deceleration environment to maintain the helmet/head of the ejectee on the headrest.]

Figure ES3
Head Force Normal to Spine Comparison

Task 2 included an assessment of the operational and performance capabilities of future (year 2000 and beyond) DoD aircraft. The assessments were based on current and previous designs developed by Rockwell International. Because of the wide spectrum of operating environments between different classes of aircraft, a data base was established for each type of future DoD aircraft to define the associated ejection / escape environment. Flight envelope parameters considered critical to successful ejection included maximum dynamic pressure, load factors, Mach numbers, altitudes, stability margins, and maximum attitude angles and rates. Some aircraft types also had unique operational requirements such as terrain following and carrier suitability. All of these factors were collected or projected for future aircraft in order to establish proper crew escape requirements.

The aircraft concepts generated were based on a set of specific mission categories. These categories included trainers, close air support, air superiority, tactical and strategic bombing, special operations, and hypersonic reconnaissance and strike. A number of aircraft concepts were identified to fit these mission categories; namely, the Air Superiority Fighter, Multi-Role Fighter, Close Air Support Aircraft, Attack Aircraft, JPATS Trainer, Strategic Bomber, Special Operations Transport, and Hypersonic Intercepter/Reconnaissance Aircraft. Table ES-1 summarizes aircraft and missions match.

In general, it was concluded that the flight envelopes of the different aircraft classes could be broken into three distinct groups: subsonic, supersonic and hypersonic designs. The hypersonic concepts were unique in that they added the additional factor of high temperature due to aerodynamic heating. It was found, however, that load factor envelopes of the different aircraft classes were more mission dependent than speed dependent. Terrain following operations were also found to be a function of the mission; however, the associated speed and altitude during penetration was highly dependent on the expected threats and the signature level of the aircraft. Takeoff and landing speeds did not vary significantly between the configurations with the exception of the hypersonic reconnaissance vehicle which showed markedly higher speeds during these phases. Finally, the vehicle stability margins were very configuration dependent, and were especially noteworthy for combat aircraft concepts which are moving more and more towards unstable designs for increased maneuverability. Figure ES4 shows the aircraft flight envelopes.

Table ES-1. Aircraft and Mission Types Match

Mission Type	Existing System(s)	Rockwell International Study
Air Superiority	F-15	Initial ATF Study
Fighter	F-16	Multi-Role Fighter Study
Close Air Support	A-10	Close Air Support Study
Attack	A-6 / A-7	Initial AX Study
Primary Trainer	T-37	JPATS Study
Strategic Bomber	B-1B	BX Study
Special Operations	MC-130	SOF Study
Hypersonic Interceptor	None	Hypersonic DLI Study
Hypersonic Reconnaissance	None	SSTO Study

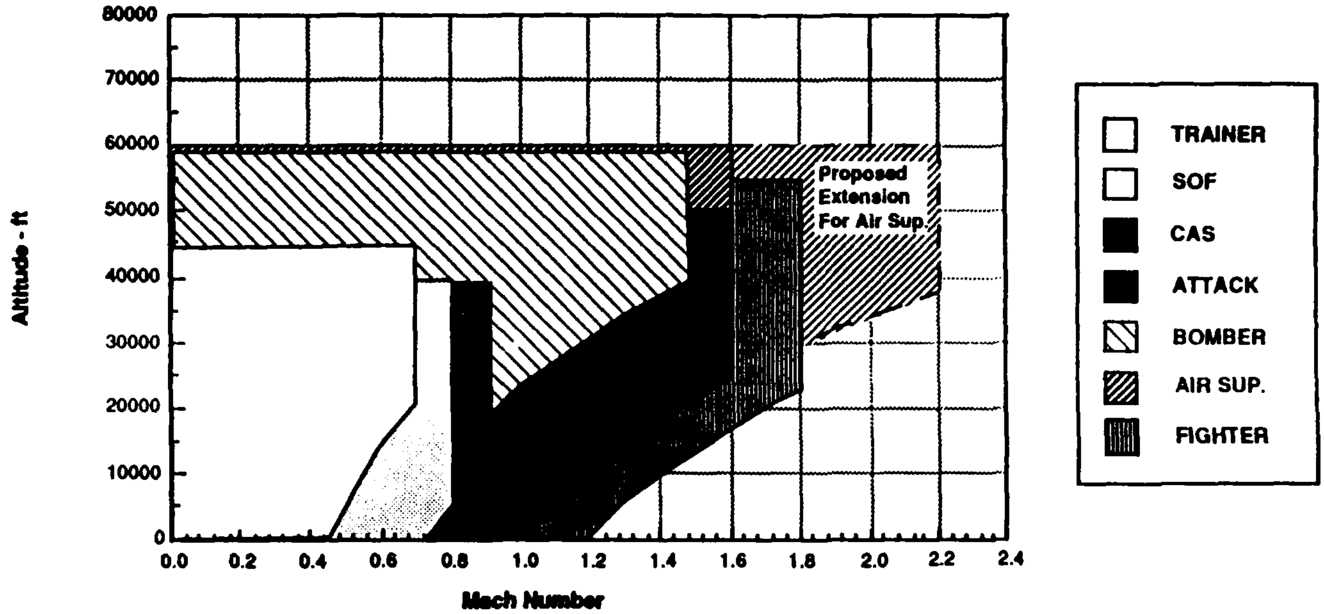


Figure ES4
Future DoD Aircraft Flight Envelope Comparison

Because of the wide spectrum of requirements associated with the various future aircraft concepts, it would be difficult to formulate a sensible set of escape system performance requirements responsive to all of the aircraft performance capabilities. Designing a system to meet all of these performance capabilities would likely exceed any reasonable cost and weight allocations, and may well not be technically achievable. Moreover, designing several different systems to respond to future user needs will also likely exceed cost allocations. To reduce costs and still meet the spectrum of performance requirements, a common baseline ejection system may be developed. Then for each of the aircraft types, modular components can be added as needed to meet the appropriate requirements. This would allow the user to focus its energy and resources towards a single ejection system development program.

Task 3 compared third generation escape system performance to the performance parameters generated in Task 2 for the future DoD aircraft. Specifically, all but the hypersonic concepts were used. [The climb to cruise and descent to landing profiles of the hypersonic concepts were such that even the most optimistic open ejection system performance envelope would only cover a few minutes of the total aircraft flight time. Therefore, it seemed unreasonable to include these concepts in this effort.] The U.S. Air Force aircraft emergency escape design guide, and the U.S. Air Force ejection seat specification, MIL-S-9479B, were used in this study to define the design goals to be met by the third generation escape systems. The CREST System Specification was used in this study as the existing design goal performance level for fourth generation escape systems.

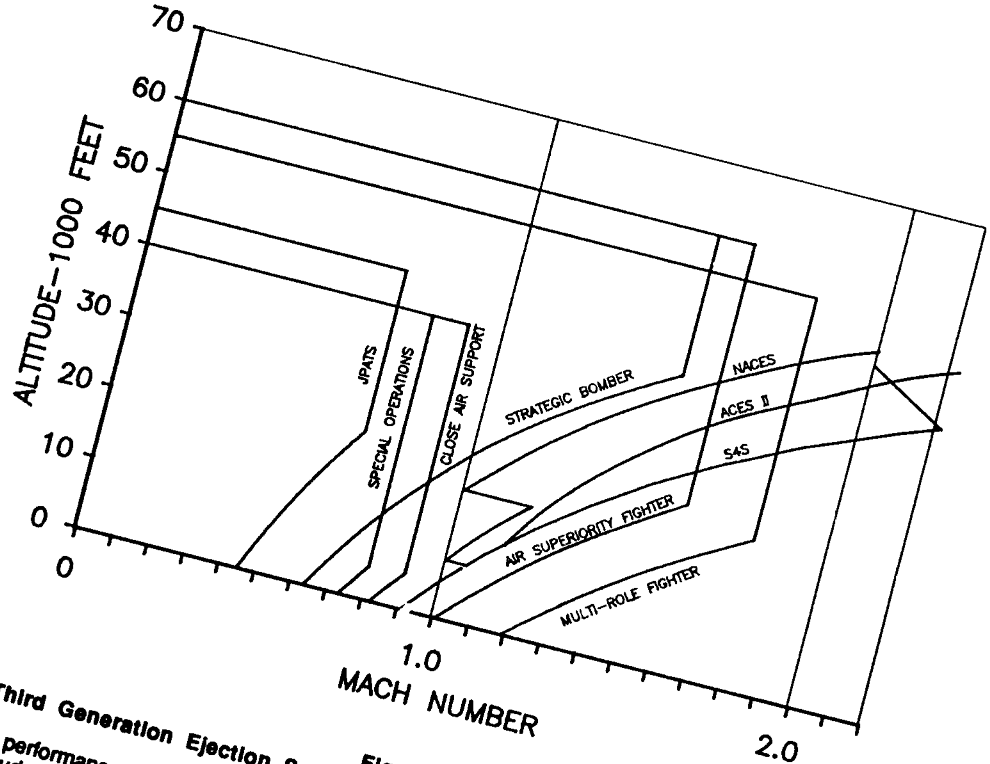


Figure ES5
Third Generation Ejection Seats and Future Aircraft Performance Comparison

The performance capabilities of third generation escape systems as presented in this task were based on the study performed under Task 1. Since the data available on these third generation escape systems did not cover certain areas of interest, best estimates had to be made. Three specific parameters were considered in this comparison, Mach number versus altitude, seat/man collision with the wings or empennage versus aircraft roll rate at ejection, and aircrew personal protection equipment limits versus anticipated aircraft performance.

It was concluded that no third generation escape system would provide safe escape at the performance levels predicted for the Attack, Air Superiority Fighter, and Multi-Role Fighter type of aircraft. Moreover, the upgrades proposed to date did not give assurance of safe escape up to the levels required by these three future aircraft. However, they did appear to provide sufficient escape performance levels for the JPATS, Special Operations, Close Air Support and Strategic Bomber future aircraft. Furthermore, after comparing the ejection limits of current aircrew personal protection equipment with the performance characteristics of the future aircraft it was demonstrated that the equipment was deficient in providing protection for safe escape throughout the entire performance envelope of the Future Air Superiority Fighter, Multi-Role Fighter and Attack Aircraft. Figure ES5 shows the aircraft and escape performance envelopes comparison.

Task 4 compared the escape system requirements of future high performance aircraft with the capabilities of fourth generation escape systems. The future aircraft performance capabilities used were again based on the results of Task 2. The CREST System Specification and the USAF Guide

Specification were used to define the design goal performance levels for the fourth generation escape systems. These documents were reviewed for adequacy in providing the necessary system requirements to ensure that fourth generation ejection systems would meet the expected performance of the future DoD aircraft studied. Figure ES6 shows a comparison of the future aircraft performance envelopes to the current CREST Design Specifications. This effort resulted in numerous recommended changes to the CREST Specifications document which serve as the general conclusions for this task. These change recommendations are summarized below, and in detail in section 2.4 of this report.

(1) In paragraph 3.1.f change 700 to 787.
(2) In paragraph 3.1.7.1 add cycles/flight, retraction distance and force for various elements of positioning and restraint system.
(3) In paragraph 3.2.1.1.1 change 700 to 787.
(4) Revise figure 4 to be compatible with (3) above.
(5) In paragraph 3.2.1.1.3 change -5g to -9g.
(6) In Table 4, next to last column, change S_Z to S_X.
(7) Include a figure giving the overall envelope requirements and reference in paragraph 3.2.2.
(8) In paragraph 3.2.2.3 add the actual crash load requirements.
(9) Eliminate requirement d (4,000 lb drogue load) from paragraph 3.2.2.3.1.
(10) In paragraph 3.2.2.3.1 change 1,660 to 2,100.
(11) In paragraph 3.2.7.1 change 700 to 787.
(12) Revise paragraph 3.7.1.1.1 to require or permit an automatic ejection initiation system.
(13) Revise paragraph 3.7.1.1.2 to make maximum strap force, accelerations and haulback times compatible.
(14) In paragraph 3.7.1.1.2 change -4 G_Z to -5 G_Z.
(15) In paragraph 3.7.1.3 change 700 to 787.
(16) In paragraph 3.7.1.7.2 change 700 to 787.
(17) Add a figure (graph) or table to define maximum parachute loads and reference in paragraph 3.7.11.2.
(18) In paragraph 3.7.2.4.3 change +4g to +5g.

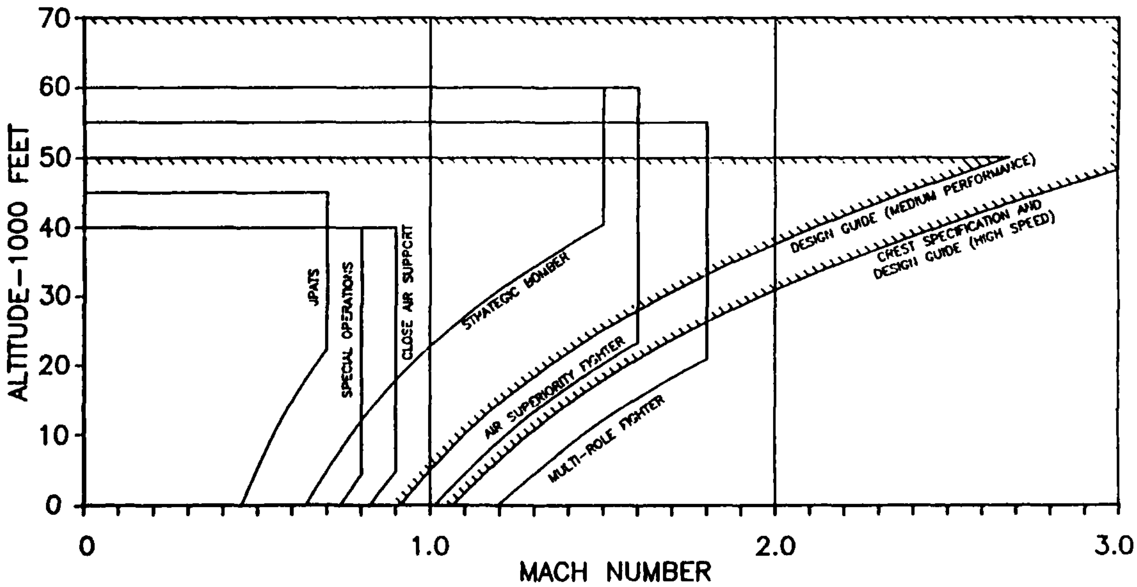


Figure ES6
Future Aircraft and Specification Performance Comparison

Conclusions/Recommendations. In all, the CREST Mission Area Requirements Study was successful in identifying ejection system performance improvements necessary to meet the predicted flight and mission envelope characteristics of future, year 2000 and beyond, aircraft. The current third generation systems served as a firm basis from which to baseline system performance, and confidently measure increments due to third generation seat product improvement programs, and proposed fourth generation seat concepts. The future aircraft concepts used were equally important by providing realistic performance goals from which the comparisons could be performed, and sound design specification change recommendations could be made. The effort and results of this study provide initial insight into the steps necessary to realize even higher crew ejection survivability for the next generation ejection system.

The results of the CREST study lead to several specific recommendations for continuing the mission area requirements investigation. Foremost, it was recommended that a more systematic methodology be employed to establish functional requirements for the next generation escape system. This recommendation included implementing a Quality Function Deployment (QFD) process that would aid in developing, evaluating, and prioritizing escape system functions and requirements for future systems application. The key element of the QFD philosophy is that it emphasized customer (user) involvement in carrying out the process. The QFD process features: 1) the orderly transition of ideas (from requirements to functions to design characteristics to technologies); 2) the gradual buildup of the complexity of the integrated design; 3) a Ramification Analysis which would insure that all relevant constraints and degrees of freedom which impinge on the design are considered, and 4) specific team and resource planning strategies.

In addition to implementing the QFD process, it was also recommended that more engineering analyses and tests be performed to formulate solutions to the more immediate problems of inherent seat instability, and human survivability in high dynamic pressure ejection environments. This included further investigation into the driving forces imparted on the ejection system during the critical phases of the ejection sequence where seat stability is a life or death issue. These critical phases included seat separation from the aircraft forebody, transition through the forebody flow field, and initial deployment of stability devices. Understanding the relative magnitude of the effects that these driving forces have on seat stability and occupant survivability would lead to proposed solutions for the next generation of ejection systems. Moreover, it was recommended that these proposed solutions be considered as design increments to an overall modularized seat concept. This concept would incorporate a baseline seat with some minimal performance capability, and the additional ability to be upgraded in terms of dynamic pressure, Mach, and altitude performance (high or low) by adding specific subsystem components to the baseline seat. This would allow the user to focus its energy and resources on one specific seat development program with a common goal, ensuring that the survivability rate of the next generation ejection system approaches 100%.

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List of Acronyms

AGL	Above Ground Level
ATF	Advanced Tatical Fighter
BCA	Best Cruise Altitude
BCM	Best Cruise Mach Number
CAS	Close Air Support
CTOL	Conventional Takeoff and Landing
DLI	Deck Launched Interceptor
DOD	Department of Defense
JPATS	Joint Primary Aircraft Training System
MRF	Multi-Role Fighter
NAA	North American Aircraft
NASP	National Aerospace Plane
PATS	Primary Aircraft Training System
SOF	Special Operations Forces
SSTO	Single Stage To Orbit
STMD	Short Takeoff - Highly Maneuverable Demonstrator
STOL	Short Takeoff and Landing
TA	Terrain Avoidance
TF	Terrain Following
VFR	Visual Flight Requirements
VSTOL	Very Short (or Vertical) Takeoff and Landing

1.0 Introduction

1.1 Background/Problem. The past twenty years of crew escape system's research and development has seen most of the development activity aimed at the third generation of ejection seats where performance requirements are stated in MIL-S-9479B dated March 1971. The Crew Escape Technologies (CREST) advanced development program is concentrating on the technologies for the development of escape systems for aircraft of the year 2000 and beyond, such as the proposed Multi-Role Fighter. Approximately ten years ago the CREST program estimated requirements for a fourth generation ejection seat and began the technology development process. Today, a reassessment of the requirements for a fourth generation ejection is needed. The capabilities of the existing third generation seats and their planned improvements is also needed along with an analysis of future aircraft requirements. The fourth generation ejection seat requirements need to be analyzed against future aircraft requirements and either reaffirmed or modified.

1.2 Objectives. The main objective of the CREST Mission Area Requirements Study was to provide an updated look into the operating environment and associated required performance of the next generation of ejection systems. The study compiled performance data for current third generation ejection systems, and their proposed follow on improvements, for comparison to the anticipated performance of future DoD aircraft (year 2000 and beyond). The comparisons were used to identify specific areas where ejection systems had performance deficiencies relative to the anticipated performance of the future aircraft concepts. With these deficiencies outlined, ejection system design performance specifications including the CREST Systems Specification for fourth generation ejection seat development were reviewed, and specific change recommendations were made to ensure that fourth generation seat concepts incorporate the performance goals necessary to meet future DoD aircraft capabilities, and improve ejection survivability.

1.3 Approach. Rockwell teamed with Logistics Management Engineering Inc. (LME) to organize and execute the technical approach to the CREST program. *Four specific tasks were outlined within the* technical approach. Task 1 - Third Generation Escape System Performance Comparative Analysis - was used to compile and compare performance capabilities of current third generation ejection seat systems. Task 2 - Performance Requirements of Future DoD Aircraft by Mission Type - compiled data on future DoD aircraft concepts and their anticipated performance capabilities. The concepts were based on a specified set of mission applications. Task 3 - Analysis of Third Generation Escape Systems to Meet Future Aircraft Escape Requirements - used the results of Tasks 1 and 2 to compare third generation seat performance to the predicted performance of the future aircraft concepts. This comparison identified performance deficiencies in the third generation seat systems. Finally, Task 4 - Analysis and Recommendations for Fourth Generation Escape System Performance Requirements - was used to review results from Tasks 1 through 3, and apply findings to the CREST System Specification. This included making specific change recommendations to the Spec to better ensure that fourth generation seat systems adequately meet the performance goals of future DoD aircraft. Results of the four tasks are presented in the following sections of this report.

2.0 Technical Results of the CREST Study

2.1 Task 1 - Third Generation Ejection System Comparisons

2.1.1 General Evaluation of Escape System Components Performance. The purpose of this Task 1 effort was to perform a study on four ejection seat configurations which have been identified as candidate third generation escape systems. This study does not intend to address how a particular seat configuration compares to another, but compares third generation seat performance trends against the Air Force's Ejection Seat General Specification MIL-S-9479B dated 1971. The configurations evaluated were the ACES-II seat developed by the Douglas Aircraft Division of the McDonnell-Douglas Aircraft Corporation for the Air Force in the early 1970's; the unqualified ACES-II PLUS modification to the ACES-II seat recently completed by McDonnell-Douglas; the NACES seat developed by the Martin-Baker Company for the U.S. Navy and qualified under the MIL-S-18471G, Ejection Seat General Specification and the unqualified S4S ejection seat developed by the Stencel Aero Engineering Corporation in the mid 1980's (which is a product upgrade of the SIIIS-3 configuration qualified by the NAVY under MIL-S-18471D.) It should be noted that there exists many differences in technical philosophy between the two service specifications but that overall objectives are relatively comparable. Under this task a comparison of these seats has been performed based upon data made available to LME by the Navy, Air Force and Universal Propulsion Company.

Before entering upon the comparative analysis which begins in Section 2.1.2, a more general evaluation of those subsystems which have direct input into the recovery performance of the escape system was deemed necessary. This general evaluation although somewhat subjective, is based on the experience of LME personnel and is considered essential information as a background to perform the comparative analyses of the third generation escape systems.

The components making up the escape system which acting together provide the total system recovery performance include at least the following:

- Restraint Harness and Powered Inertia Reel Device
- Propulsion Subsystems
- Pitch/Yaw Stabilization Subsystems
- Altitude/Airspeed Sensing Subsystem
- Post Ejection Sequencer
- Main Recovery Parachute Subsystem

The contributions of each of these devices or subsystems must be individually optimized in performance throughout the total airspeed regime in order that the total escape system performance will be truly optimized. The optimization of the performance of each of these items must be carried out on the basis of the total pilot population, the complete altitude/airspeed envelope required, the minimum time for safe recovery, and the physiological limits of the human body. And further, the airspeed/altitude regime wherein the majority of ejection fatalities have taken place in the last few years should be given the highest priority in any escape system optimization process if maximum benefit to the total ejectee population is to be realized.

2.1.1.1 Restraint Harness and Powered Inertia Reel Device. The escape system harness must provide appropriate and comfortable support throughout the aircraft flight regime without hindering the "Check Six" capability of the pilot. One of the most critical criteria for the evaluation of a harness is its capability to overcome negative Gz forces. As the aircraft performance capability has advanced to ever higher acceleration levels, this negative Gz restraint problem has become more severe. Those harnesses which depend only on the lap belt to resist these upward forces cannot prevent either separation of the wearer's buttocks from the seat pan surface or elongation of the spine. Only those harnesses which provide firm over-the-shoulder restraint to the seat pan without restricting easy and comfortable "Check Six" aftward viewing can successfully prevent helmet to aircraft canopy impact in the severe negative Gz environments which are encountered in modern aircraft. Lap belts, including those with negative G straps, do not prevent some upward displacement of the seat occupant off the seat pan surface and upon ignition of the catapult the seat will build up a velocity before impacting the ejectee's

buttocks. If this impact and the resulting velocity change of the base of the spine is large enough, a back injury can be experienced. This is true even though there is indication, based on work done by the Air Force, that some pre-compression of the spine before the catapult acceleration level increases to its maximum may be beneficial. The Air Force PCU-15A/16A Harness and the Navy MA-2 Torso Harness both depend on the lap belt for negative Gz restraint. Therefore, these harnesses are considered deficient under certain maneuvers in high performance aircraft that are already in the inventory. When the next generation of aircraft, such as the ATF, are introduced even higher levels of upward, downward, sideward, forward and aftward accelerations will be possible and harness improvements will definitely be needed.

Under negative Gx accelerations at the time of an ejection, pilot submarining under the lap belt appears to be possible in Air Force aircraft which are equipped with seats using the PCU-15A/16A Harness which can result in a back injury during the upward catapult acceleration out of the cockpit. The new Air Force X-Band Harness as well as the Navy MA-2 Harness are able to prevent this submarining movement. In this negative Gx environment, if the pilot is leaning only a few inches forward of the seat back, both the Air Force and Navy powered inertia reel devices (PIRD) are severely limited in retracting the pilot under these accelerations, and even if the inertia reel straps are fully extended these PIRDs are only able to retract a non-resisting seat occupant under a negative 2Gx acceleration.

[Note that there is some disagreement among pilots on the necessity of the negative G strap. However, during a 1988 visit to Shaw Air Force Base, we learned that F-16 pilots were not allowed to perform an important -Gz dog fight maneuver as it may result in the pilot's arms being lifted off of the flight controls. A pilot stated that the first time he would use that maneuver would be when a live enemy was on his tail and he would have no other choice but to risk losing control of the aircraft. The -Gz restraint would maintain the pilot's arms on the F-16 consoles without impeding "check-six" capability.]

A PIRD unit being developed by the Air Force is planned to supply a really important capability in addition to its ability to provide successful retraction under higher levels of negative Gx acceleration. This capability is that it will haul back the pilot in a much shorter time without exceeding a safe maximum retraction velocity. To assess the importance of reducing the time to catapult separation in the low altitude/adverse attitude escape condition a perfunctory study was conducted of those effects which a delay from ejection seat system initiation to catapult ignition of 0.1, 0.2, 0.3, 0.4 and 0.5 second will have on the time available for parachute operation. This study considered the seat and occupant altitude as a function of time from system initiation for a standard ejection seat escape system under the conditions of a constant roll rate of 100 degrees per second both with and without a fast acting drogue at an ejection airspeed of 200 KEAS. Then the same ejection conditions were considered with the exception that the constant roll rate was 150 degrees per second and the seat was without a drogue. Appendix A includes the graphs which were developed in this study.

The important conclusion reached in Appendix A is: "Any time saving in the escape system timing prior to catapult separation is equivalent to over ten times any time saving which is made subsequent to catapult separation."

The Navy is also developing a new PIRD which will provide the capability of locking under -0.6Gx to protect the pilot against a high spin condition.

2.1.1.2 Propulsion Subsystems

2.1.1.2.1 Catapult Subsystem. Rapid safe escape from the cockpit of a crippled aircraft is a critical step in the ejection sequence. As aircraft have become more agile and have provided the pilot with the capability of maneuvering at higher acceleration levels, the possibility of ejecting under acceleration has become more probable. The closed volume catapult is the device that has been used for this purpose in open ejection seat escape systems in the past and is considered to be the appropriate device for this purpose in any future open ejection seat escape system. The rocket catapults which were first used to provide both the egress catapult and the sustainer rocket in a single unit had an extremely large final volume to initial volume ratio of thirty to one or greater. Catapults of this design can be very susceptible to over loading the ejectee's spine in the presence of any positive aircraft Gz at the time of ejection or if any other resisting forces were acting in opposition to the separating movement of the catapult. In the more recent catapult designs this final volume to initial volume ratio has been greatly reduced to three to one or less to alleviate this undesired condition. However, even these state-of-art catapults will produce unacceptable acceleration levels when aircraft positive Gz accelerations are greater than two or three.

Third generation escape system catapults generate very high DRI values for ejections under positive Gz levels of only three, five or seven which are sufficient to cause severe spinal injury and even death. An improved catapult subsystem is considered to be essential for the development of the fourth generation escape system.

In Appendix B two recent approaches to the design of a catapult which would have the capability of functioning under positive Gz levels up to as much as seven g's without severely overloading the ejectee's spine are discussed.

2.1.1.2.2 Sustainer Rocket. The sustainer rocket was first added to ejection seat escape systems over thirty years ago to provide greater escape velocity away from the crippled aircraft. This greater velocity would provide a higher trajectory sufficient to assure tail clearance in ejections at high speeds and to allow time for recovery parachute inflation in ground level, low speed ejections.

In general it appears that the sustainer rocket thrust will provide the best overall system recovery performance if it is acting in a forward and upward direction approximately forty-five degrees forward of the seat bucket back plane. In a zero forward airspeed ejection it is most important to have a sizeable forward velocity of the seat/ejectee generated by the sustainer rocket to overcome the aftward velocity component generated by the catapult because of the nose-up catapult angle in the aircraft. This is essential in fast operating systems where the parachute is deployed on the ascending portion of the trajectory to prevent the possibility of the ejectee falling back into the opened parachute under the action of earth gravity. In an extreme high airspeed ejection as the seat rotates nose-up during and after tipoff it is advantageous to have the sustainer rocket thrust vector pointed in a more vertical and less aftward direction to improve tail clearance as well as to lower the spinal compression loading of the ejectee. This forty-five degree forward angle also provides a thrust vector which is more nearly parallel to the major axis of the cg ellipse representing the total pilot population with all possible personnel equipment variations.

2.1.1.3 Pitch/Yaw Stabilization

2.1.1.3.1 Pitch Stabilization

2.1.1.3.1.1 Low Speed Pitch Stabilization. Low speed pitch stabilization systems for ejection seats have been available since the mid nineteen-sixties. The Stencel DART system and the Douglas STAPAC system have been used in most of the American made systems since that time and the recovery record of those ejection seat escape systems which provided pitch stabilization has shown a marked improvement in this very low speed ejection environment. Anthropometric differences in the male pilot population as measured in the early nineteen-sixties indicated that the cg variation perpendicular to the line passing through the anthropometrically correct fifth and ninety-fifth percentile pilot cg locations was over plus/minus one-half inch. When the variations in personnel equipment was included this variation increased to over three-quarters inch. Therefore, by the early nineteen-seventies both the Navy and the Air Force had included in their ejection seat design specifications the requirement for pitch stabilization for static cg variations of up to plus/minus one inch (MIL-S-18471C, Navy) and plus/minus two inches (MIL-S-9479B, Air Force).

2.1.1.3.1.2 High Speed Pitch Stabilization. In an ejection at higher airspeeds the deceleration drogue provides pitch stabilization after it has inflated. Since the late nineteen-sixties the deceleration drogue has been incorporated into every open ejection seat escape system which was designed for escape at airspeeds up to 600 KEAS. Historically, the Martin-Baker systems had a drogue design giving a feet first attitude in the airstream. Because of the concern over the spinal (+Gz) loading in this feet first attitude most, if not all, other systems had drogue designs which gave a face forward attitude in the airstream. In this face forward attitude longitudinal accelerations (-Gx) up to thirty-five G were believed to be acceptable. Different means were used to deploy the drogue into the high speed airstream. Slug deployed single or dual drogue systems were most popular. Mortared drogues have also been used to provide faster deployment. Unfortunately, in ejections at airspeeds above 500 KEAS, the tipoff of the seat during guide rail separation often caused severe nose-up pitching before the drogue was able to provide pitch attitude stabilization. During this time period of unstabilized pitching the seat and ejectee would be exposed to the most severe dynamic pressures that would occur throughout the entire

escape history. Thus efforts have been made to speed up the drogue deployment and inflation process in the third generation escape systems.

2.1.1.3.2 Yaw Stabilization

2.1.1.3.2.1 Low Speed Yaw Stabilization. Seat yawing in the very low airspeed ejection environment has not been considered to be a major problem in the past. In some third generation systems the drogue is not deployed in the low speed mode and no other means for yaw stabilization is provided. Coupling between any roll inputs for providing trajectory divergence and seat yawing is consistently observed in dual seat systems and severe yaw attitudes at the time of main recovery parachute opening are often experienced in such systems.

2.1.1.3.2.2 High Speed Yaw Stabilization. Seat yawing in high speed ejections is and has been long considered to be a major problem. Deceleration drogues have been designed with three and four leg bridles to positively control the seat in a face forward attitude in the high speed airstream. Thus once the drogue is inflated both pitch and yaw stabilization of the ejected seat/pilot are assured. Again, as was true for pitching of the seat, severe yawing of the seat prior to drogue inflation has been the norm in high speed ejection tests where relatively rigid anthropometrically correct dummies are utilized. The generally accepted limit for a lateral acceleration (plus or minus Gy) is only fifteen G. Thus yawing past twenty some degrees in an ejection at 600 KEAS will result in out-of-specification lateral accelerations.

Many years ago wind tunnel tests were performed on seats with yaw stabilization vanes or plates by the Air Force. These tests showed that yaw stabilization of an ejection seat could be achieved by such devices provided they were large enough and were located at a sufficient distance behind the seat/occupant cg. Based on these test results yaw stabilization fins were incorporated into a seat design and tests were performed at several different ejection airspeeds up to 600 KEAS. Although these yaw stabilizer fins were designed to minimum dimensions the reduction in seat yawing at all airspeeds was considered dramatic. More recently the use of a gyro to rotate the sustainer rocket for yaw stabilization has been successfully tested at different airspeeds up to 700 KEAS. No third generation escape system in actual use has incorporated such high speed yaw stabilization before the drogue becomes active.

2.1.1.4 Airspeed/Altitude Sensors. In the nineteen-fifties North American Aviation designed a dual mode sequencing system for their HS-1 ejection seat. This seat incorporated an airspeed and altitude sensor which was tied into the aircraft Pitot system to provide the necessary intelligence for mode selection. In the late nineteen-sixties Douglas Aircraft designed their ACES-I ejection seat with a similar mode selection system. This system utilized seat mounted Pitot tubes for airspeed and altitude sensing as required for mode selection. Since that time most third generation escape systems have incorporated multimode sequencing with on seat sensors which are independent of the aircraft.

It would appear that the effects of the detached normal and oblique shock waves which will always exist to some degree ahead of the ejected seat in a supersonic airstream have been mostly ignored in the third generation ejection seats (except for the Advanced Recovery Sequencer used in the ACES-II PLUS seat). Such shock waves increase the sensed static pressure, indicating a lower altitude than actual, and they reduce the sensed dynamic pressure, indicating a lower airspeed than actual. If mode selection is made before the seat decelerates to a subsonic condition a very early and probably catastrophic parachute deployment would occur. This shortcoming should not be overlooked in any fourth generation ejection seat.

2.1.1.5 Post Ejection Sequencer. One of the most important functions of any escape system is the provision of recovery parachute operation at the appropriate time for safe and non-injurious recovery of the ejectee. Third generation ejection seats which are now in service use incorporate two or more fixed time delays which can be selected based upon the airspeed and altitude conditions prevailing at some point after the ejection seat exits from the aircraft cockpit. In such systems it is necessary to have the ability to measure the prevailing airspeed to an acceptable accuracy throughout the complete speed range and to set the timing of each mode for the worst combination of conditions which will require the longest time period to decelerate to the maximum safe speed for parachute deployment. These worst case conditions should include a ninety degree dive angle, the hottest expected summer temperature,

the heaviest system ejected weight, and the highest altitude/airspeed for the sequencing mode in force. Then it should be evident that ejections under all other less severe conditions will pay a time penalty which could be critical to the survival of the ejectee due to this longer than necessary time delay for deceleration to a velocity safe for parachute deployment. These time penalties are not negligible and can be easily overcome.

One third generation ejection seat has a very simple post ejection sequencing system which eliminates any unnecessary time delay to parachute deployment under all conditions. This sequencing system continuously senses the airspeed and altitude environment and only when the ejected seat and its occupant have decelerated/fallen to the maximum safe parachute deployment airspeed and/or altitude will the signal for parachute deployment be provided. A very important feature of this sequencer is that it only needs to have accurate sensing and measurement of the airspeed in the range of 275 KEAS to 325 KEAS at pressure altitudes up to 15,000 feet. Appendix C includes the results of a study performed several years ago of the time saving which the continuous sensing system provides for some combinations of conditions. This sequencing does require that the seat mounted Pitot tubes continuously sense the prevailing airspeed and altitude to some lower level of accuracy. This requires that the seat be more yaw and pitch stable through the deceleration phase of a high speed ejection than is necessary for mode selectable fixed time delay sequencing systems.

2.1.1.6 Main Recovery Parachute Subsystem

2.1.1.6.1 Deployment. The optimum parachute deployment vector at all airspeeds is directly downstream. At very low airspeeds downstream deployment of the parachute will assure very important time savings both in the time to reach down stream line stretch and in the time required for development of the canopy to its fully inflated condition. At high airspeeds downstream deployment of the parachute will encourage symmetrical loading of the canopy and will align the canopy apex vent with the high velocity air initially entering the canopy skirt. Both of these effects act to increase the maximum airspeed at which the parachute may be deployed without canopy damage or without exceeding maximum parachute opening shock force/acceleration limits of the ejectee. Deployment of the parachute directly downstream also permits the use of inflation aids as well as inflation control techniques such as automatic high speed reefing. The bottom line is that directly downstream deployment of a parachute makes its inflation performance safer, more reliable, more repeatable and on the average more rapid, while making it possible for it to have a higher maximum pack opening airspeed capability.

The advantage of a higher parachute maximum pack opening airspeed apparently may not be sufficiently appreciated by escape system designers. Appendix D includes some graphs of the airspeed decay in the level flight 600 KEAS ejection condition and in the ninety degree dive 600 KEAS ejection condition. The absolute necessity of performing overspeed testing of the recovery parachute assembly is clearly indicated in Figure D1 wherein the airspeed in the ninety degree dive condition is over twenty KEAS higher than in the level flight condition by the time the ejected seat has slowed to 250 KEAS. Based on the curves in Appendix D it is believed that a fifteen percent saving in the altitude required for recovery of the ejectee in a 600 KEAS, severe nose down ejection condition can be realized by having a parachute system truly capable of pack opening at airspeeds of 300 to 325 KEAS.

2.1.1.6.2 Development. T. W. Knacke gave a series of lectures in 1985 during the Sandia National Laboratories Short Course sponsored by the University of Minnesota in which the parachute development (sometimes referred to as inflation, or more often as filling) process was discussed in detail. The main point in the unaided or unrestricted development of a given parachute canopy design is that a particular canopy diameter will inflate in a distance that is nearly independent of the initial velocity of the airstream. A reefing line can be added to slow the high speed development of a canopy as has been utilized in the ACES-II parachute assembly. Line cutters have been used to disreef the canopy in most reefed canopy recovery systems, however the use of automatic reefing/disreefing techniques has been successful in some parachutes. One requirement for automatic or controlled disreefing is that it must not distort the canopy mouth to overload some panels and to offload other panels. The desired feature of such controlled disreefing means then is that every suspension line is acted upon in the identical manner to achieve a perfectly symmetrical opening of the canopy mouth during the complete development or filling process.

The most recent controlled disreefing technique which has been successfully tested is that used in the Irvin AIM parachute. In this parachute a line attached from the AIM canopy apex to the center of the Webb chute in the canopy mouth acts to pull every suspension line inward during the complete development process and thus forces the canopy mouth into a circular shape while retarding the outward movement of the canopy mouth. Over twenty-five years ago the Mark Hatten automatic reefing system in the C-9 canopy was successfully tested at an extremely high airspeed of over 400 KEAS at El Centro, but due to weight and reliability restrictions this automatic reefing/disreefing method was not pursued further. In this reefing technique the force in each suspension line acted to pull the canopy skirt inward such that each line with a greater than average force level would restrict its adjacent panels from filling out and those with a less than average force level would allow its adjacent panels to fill out until the force level increased to the point that further expansion would not occur.

Dr. H.G. Heinrich working with the Pioneer Parachute Co. in the 1950's tested a canopy similar to the C-9 which had extensions below the canopy skirt on every other panel. These added extensions deformed inward during canopy development to act as small aerodynamic surfaces which generated an inward force resisting the outward movement of the canopy skirt thus slowing the high speed canopy development (desirable) as well as the low speed canopy development (undesirable). These panel extensions also gave a desirable reduction in the canopy oscillation during steady state vertical descent as well as adding slightly to the canopy drag area when it was fully inflated.

In this same time period Dr. Heinrich added a very small parachute in the mouth of the main canopy to more rapidly force the canopy mouth outward to some small diameter which not only would act to speed up the canopy development but would also make it much more repeatable. The Webb chute in the mouth of the AIM parachute makes use of this capability and has added the concept of radial lines from the Webb chute out to every suspension line for control of the canopy mouth into the very desired circular shape.

During the late 1950's and into the 1960's the spreader gun inflation aid was developed for more rapid development of a parachute canopy to full inflation even in a near zero speed airstream. This inflation aid was qualified in the C-9 canopy first by the Navy and later by the Air Force for use in Upgrade Kits for older ejection seats to bring them up to a zero-zero ejection capability. This device was also used in the SIIIS-3 ejection seats designed for application to the AV-8A Harrier aircraft with its vertical takeoff capability. Due to its high rate of G onset, about 200 G/second, this device may increase the injury potential to the ejectee.

In very recent years the use of square form gliding parachutes has been strongly advanced by many of its proponents in the parachute community and great strides have been made in its high speed opening performance. Two important characteristics of such a gliding parachute must be carefully evaluated before it can safely be added to an ejection seat escape system. First, in very low level ejections the ejectee either may not be physically able to successfully operate the gliding feature of this parachute into an upwind direction, which is required if the ground impact injury hazard is to be reduced, or it may not be possible, even if he were able, to turn the parachute into this direction due to the shortness of time to ground impact. Then second, if the gliding parachute in very low level ejections is oriented in the airstream during canopy development so as to have its direction of drive downward rather than upward or sideward, which will occur approximately twenty-five percent of the time, then the hazard of ground impact injury is greatly increased. Therefore, such a parachute should initially open in a non-gliding configuration and in this configuration must not have a greater vertical descent velocity nor a greater oscillation angle than that of the C-9 canopy if the injury hazard levels at ground impact are not going to be increased.

In summary it can be stated that the present state-of-the-art parachute technology does not provide the extreme fast opening obtained with a spreader gun aided canopy inflation in the extreme low speed regime and with the controlled, slower opening provided by the automatic reefing/disreefing capability in the very high speed regime. The development of a parachute subsystem offering these performance advantages for the fourth generation escape system appears to be very desirable and should be within present day capabilities of the parachute community.

2.1.2 Evaluation of Third Generation Escape Systems Performance. The third generation ejection seat escape systems which have been evaluated include the ACES-II (and its modification, the ACES-II PLUS), the NACES and the S4S. A very limited number of tests were performed on the S4S. All the data recorded on this system was available for analysis. Table VI in Section 2.1.3 is a listing of the test results for these tests. Data from over thirty tests of the ACES-II seat was received from the Air Force

which covered most of the System Qualification testing and the High Technology Cockpit Compatibility testing. Tables VII, VIII and IX also in Section 2.1.3 list the test results from these tests. Data for fifty tests of the NACES was obtained from the Navy which covered many of the Cockpit Compatibility tests for the T-45, F-18 and F-14. Tables X through XV also in Section 2.1.3 list the test results from these tests.

The requirements of MIL-S-9479B for the performance of the six subsystems listed in Paragraph 2.1.1 have been cursorily compared to the estimated performance of these subsystems in the S4S, the ACES-II and the NACES ejection seats based upon computer studies of shock wave effects as well as upon the test data recorded in track and/or flight system tests. No test data was available for the ACES-II PLUS ejection seat and only very limited data was available for the S4S ejection seat. Tables I through V provide these comparisons in tabular form.

Figure 1 provides a listing of the components and/or subsystems used in these third generation escape systems for each of the six primary functions of the ejection seat as listed in Section 2.1.1 and discussed in Subsections 2.1.1.1 through 2.1.1.6 above. Each of these six functions for each of the third generation escape systems will now be addressed.

2.1.2.1 Restraint

2.1.2.1.1 S4S Ejection Seat. The restraint developed for the S4S is the IH-1 harness which has not been qualified for operational ejection seats. A major attribute of this harness is that it provides the pilot with negative Gz restraint capability. The IH-1 harness utilizes over-the-shoulder support of the wearer to prevent upward movement of the shoulders. The PacSci P/N 0113700-03 powered inertia reel device is used in the S4S to protect the pilot against forward motion under negative Gx and to retract him/her upon ejection from a forward lean attitude. This PIRD has limited strap force levels and cannot haul a ninety-eighth male pilot back from a forward lean attitude under a negative Gx level greater than two. The IH-1 harness is designed to prevent submarining in a negative Gx ejection.

Leg restraint is provided in the S4S. This leg restraint system is essentially identical to that in the SIIIS-3 system for the AV-8A and AV-8B Harrier aircraft. Arm restraints have not been supplied in the S4S seat.

2.1.2.1.2 ACES-II Ejection Seat. The PCU-15A harness is presently being flown in the ACES-II seats. This harness depends on the lap belt to provide negative Gz restraint which allows the spine to elongate as well as the hips to move upward under negative Gz accelerations. The PacSci P/N 0103190-07 powered inertia reel device used in the ACES-II does not provide sufficient power haulback forces to assure the ninety-eighth percentile male pilot haulback under two or more negative Gx. The lap belt and PCU-15A harness do not appear to have assured capability of preventing submarining in a negative Gx ejection. The ACES-II seats in the B1 aircraft incorporate both arm and leg restraints. These devices are qualified in the ACES-II seat and have proven to be effective in live ejections.

	S4S	ACES-II	ACES-II PLUS	NACES
RESTRAINT TORSO ARMS, LEGS	IH-1 & PIRD* LEG STRAPS	PCU-15 & PIRD* OPTIONAL	PCU-15 & PIRD* OPTIONAL	MA-2 & PIRD* LEG STRAPS
PROPULSION CATAPULT ROCKET	MK 19 MOD 0 CAT 2 MK 79 SBRs	CKU-5/A ROCAT	CKU-5A ROCAT	MBEU-14512_ MBEU-14746_
STABILIZATION PITCH YAW	DART, DROGUE FINS, DROGUE	STAPAC, DROGUE DROGUE	STAPAC, DROGUE ROCKET, DROGUE	DROGUE DROGUE
SENSING	ON-SEAT	ON-SEAT	ON-SEAT	ON-SEAT
TIMING	P/C DEPLOYMENT AIRSPEED	MULTI-MODE TIME DELAYS	MULTI-MODE, MACH SENS. TIME DELAYS	MULTI-MODE TIME DELAYS
PARACHUTE DEPLOYMENT DEVELOPMENT	WORD,# DROGUE WEBB CHUTE	MORTAR, PIL/CHU REEFING LINE	MORTAR, PIL/CHU REEFING LINE	ROCKET CONTROLLER DROGUE

NOTES: * POWERED INERTIA REEL DEVICE
WIND ORIENTED ROCKET DEPLOYMENT

Figure 1
Listing of Components/Subsystems of the Third Generation Escape Systems.

2.1.2.1.3 ACES-II Plus Ejection Seat. The ACES-II Plus seat has the same restraint capabilities as the ACES-II seat and therefore it will have basically the same restraint capability as the ACES-II seat discussed above.

2.1.2.1.4 NACES Ejection Seat. The MA-2 harness utilized in the NACES depends on the lap belt for negative Gz restraint which allows the spine to elongate as well as the hips to move upward under these accelerations. The MA-2 harness has the capability of preventing submarining during an ejection under negative Gx accelerations. The powered haulback capability of the NACES PIRD was not identified in the available data but the unit itself appears to be more rugged than the other PIRDs used in the other systems and it is expected that its powered haulback capability under negative Gx accelerations is greater than that of the other third generation escape system PIRD's.

Standard Martin-Baker leg restraint straps are provided in the NACES. It is believed this leg restraint system has a good history in live ejections of limiting leg injuries during high airspeed ejections with a high reliability. An arm restraint subsystem is not operational in the NACES at this time. The Survival Technology Restraint Improvement Program (STRIP) now being pursued by the Navy could provide NACES with over-the-shoulder negative Gz restraint, an arm restraint system and means to prevent submarining of the seat occupant under negative Gx conditions.

2.1.2.1.5 System Restraint Comparison. Table I summarizes the personnel restraints of the 3 ejection seats. The S4S with the IH-1 harness with its over-the-shoulder restraint appears to provide better negative Gz restraint as compared to the other third generation seats as they are now configured, but improved negative Gz restraint is available for these other seats.

The NACES with its apparently more powerful PIRD should provide superior powered haulback capability under negative Gx levels of two or more.

The S4S and NACES restraint configurations provide better protection from "submarining" of the seat occupant as compared to the ACES-II and ACES-II Plus restraints.

The ACES-II and ACES-II Plus seats as configured in the B1 aircraft provide better arm restraint in high speed ejections as compared with the S4S and NACES seats as they are now configured.

All the third generation seats provide leg restraint in the high speed airstream and appear essentially equal in this capability.

2.1.2.2 Propulsion

2.1.2.2.1 Catapult

2.1.2.2.1.1 S4S Ejection Seat. The Mark 19 Mod 0 catapult is used in the S4S seat. This catapult was qualified by the Navy for the SIIIS-3 seat. This catapult is fixed to the aircraft such that the seat bucket moves up and down relative to it when the seat height is adjusted. This design allows up to five inches more catapult stroke as compared to a design wherein the catapult is fixed to the seat and moves up or down relative to the aircraft when the seat height is adjusted. Also it assures that a constant displacement between the top of the seat and the cockpit canopy is maintained for all seat height adjustments. The Mark 19 Mod 0 catapult is a dual thrust unit assembly with a single cartridge mounted between the two thrust units. The cartridge has two redundant igniters, one on each end, each igniter having two percussion primers in it for maximum reliability. This catapult provides the energy for drogue deployment during its powered stroke and thus provides reliable drogue deployment whenever the catapult is fired to eject the seat from the cockpit.

This Mark 19 Mod 0 catapult assembly produces a catapult separation velocity of between forty-six and forty-nine FPS under the one Gz earth gravity condition with recorded DRIs from thirteen to sixteen. Tests have not been performed on this catapult at higher levels of positive Gz, but injurious DRI levels can be expected at the positive seven or higher Gz condition.

The Mark 19 Mod 0 catapult assembly incorporates separate and redundant pressure ports, one in each of the dual thrust unit assemblies, for initiation of post ejection sequencing functions of the seat. These pressure ports are located so as to output the catapult pressure when the seat has travelled to within seven and one-half inches of the end of catapult stroke to provide the desired ignition timing of the seat back rockets (SBRs).

An important feature of the dual thrust unit catapult design is the saving in the fore and aft cockpit space required for the crew station which is realized. In his article, "Some Influences of Aero Medical Data on Aircraft Design", in the December 1954 issue of Aviation Medicine, A. M. Mayo of the Douglas Aircraft Company demonstrated that a one inch saving in the fore/aft direction of the seat space requirement in the cockpit resulted in a 90 pound reduction in aircraft weight. This catapult design will reduce the distance required from the bulkhead to the ejection seat neutral seat reference point by up to three inches for a weight saving in the aircraft itself of over two hundred pounds if it utilizes this fore/aft space saving.

2.1.2.2.1.2 ACES-II Ejection Seat. The CKU-5/A rocket catapult (ROCAT) is used in the ACES-II seat to provide both the catapult and the sustainer rocket propulsion energy. Two input ports to the CKU-5/A rocket catapult supply the initiation pressure to a common plenum chamber which then feeds two pressure actuated firing pins, each with its own percussion primer, to provide it with reliable ignition.

The CKU-5/A ROCAT provides a nominal or average catapult separation velocity of forty-three FPS under the one Gz earth gravity condition with recorded DRIs from thirteen to sixteen. Tests were performed by the Air Force on this catapult at positive Gz levels of three and seven using the linear accelerator at Wright Field. Very high DRI levels were computed from the accelerations as measured in these tests.

2.1.2.2.1.3 ACES-II Plus Ejection Seat. The ACES-II Plus seat has the same ROCAT propulsion unit as used the ACES-II seat and thus is expected to have the same catapult performance capability and reliability.

Table I. Subsystem: Personnel Restraint

SUBSYSTEM: PERSONNEL RESTRAINT

	MIL-S-9479B	S4S	ACES-II	NACES
1.	PARAGRAPH 3.4.2 PREVENTION OF SUBMARINING	PREVENTED BY IH-1* HARNESS	NOT PREVENTED BY PCU-15 HARNESS	PREVENTED WHEN CROTCH STRAP IS CONNECTED
2.	PARAGRAPH 3.4.2.1 NO RESTRICTION OF MOVEMENT	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE
3.	PARAGRAPH 3.4.2.2 HAULBACK WITH 300 POUNDS AT 0-18" STRAP EXTENSION	INERTIA REEL IS MARGINAL OR DEFICIENT	INERTIA REEL IS MARGINAL OR DEFICIENT	MARTIN-BAKER REEL PERFORMANCE IS UNKNOWN
4.	PARAGRAPH 3.4.2.3 PIRD STRAP ABOVE 95TH PERCENTILE SHOULDER HEIGHT	98TH PERCENTILE HEIGHT FOR FULL UP/DOWN SEAT ADJUSTMENT	98TH PERCENTILE HEIGHT FOR FULL UP/DOWN SEAT ADJUSTMENT	98TH PERCENTILE HEIGHT IF SEAT IS ADJUSTED FULL DOWN

* THIS IS AN EXPERIMENTAL HARNESS NOT YET QUALIFIED FOR OPERATIONAL USE IN THE U.S. IT IS OPERATIONAL IN THE ARGENTINE AIR FORCE.

2.1.2.2.1.4 NACES Ejection Seat. The NACES seat uses the Martin-Baker MBEU-145120 catapult. This catapult is a single tube and piston assembly which is powered by a primary propellant charge and a booster charge. The primary charge is fired to initially propel the seat up the guide rails and only after the seat has moved up them almost fourteen inches is the secondary charge fired. Slippers mounted on the main beams of the seat engage two guide rails bolted on opposite sides of the catapult outer tube and provide the initial guidance of the seat out of the cockpit. After the seat has traveled something over twenty inches the middle pair of slippers disengage from the guide rails. The bottom pair of slippers continue to provide yaw control of the seat until they clear the guide rails, but pitch control of the seat is provided only by the engagement of the inner tube (or piston) and a bushing located on the inside of the outer tube during this time interval.

The NACES catapult is fixed to the aircraft such that it does not move relative to the aircraft when the seat is adjusted up or down. Therefore it allows a longer catapult stroke in a given cockpit vertical space requirement. It is thus expected that NACES will have a catapult separation velocity ranging from forty-six up to fifty FPS under the one Gz earth gravity condition. Catapult separation velocity data was not supplied for the track and flight tests used in this study.

The NACES catapult provides two separate and redundant ballistic latches which upon operation during the catapult stroke will retain end fittings on each of the two sequencer start switch cables. Upon sufficient travel of the seat up the catapult these two separate and redundant cables will turn the sequencer on.

2.1.2.2.1.5 Catapult Comparison. Table II compares the three propulsion subsystems to pertinent MIL-S-9479B paragraphs. The S4S and the NACES catapult subsystems will provide almost the same catapult separation velocities under the normal one Gz earth gravity condition. Due to its shorter length the ACES-II catapult produces a catapult separation velocity about four FPS less. This is not considered a major difference in the systems since the STAPAC will contribute extra upward impulse later.

The three third generation catapult subsystems will provide essentially the same catapult separation time from initiation under the normal one Gz earth gravity condition (See Figure 5 in Section 2.1.3).

The three third generation catapult subsystems appear to generate essentially the same DRI levels under the normal one G earth gravity condition, but the S4S and the ACES-II catapults will have some advantage in reliability under higher levels of positive Gz acceleration, especially when through-the-canopy capability is to be provided by the escape system, due to their single booster cartridge design. The NACES catapult with its second booster cartridge that ignites only after a catapult stroke of twenty inches, has not been designed to perform under positive Gz accelerations and neither the NACES nor the S4S has been tested under these conditions.

The S4S and NACES seats appear to have an advantage in the cockpit vertical space requirement as compared to the ACES-II and the ACES-II PLUS seats since the CKU-5/A ROCAT moves with the seat during up or down seat height adjustment. This requires that the height of the cockpit canopy for a given catapult stroke must be almost five inches greater than would be required if the catapult were fixed relative to the aircraft.

The S4S dual tube assembly has an advantage in that the cockpit fore/aft space requirement for the seat is smaller. This is an important consideration because of the appreciable weight savings which is realized when the aircraft is designed to take advantage of its smaller fore/aft ejection seat space requirement.

2.1.2.2.2 Sustainer Rocket

2.1.2.2.2.1 S4S Ejection Seat. The S4S has two each seat back rockets (SBRs) mounted to the back of the seat bucket which under many less severe ejection conditions are truly redundant in that one unit is sufficient to assure recovery. Tail clearance in very high speed ejections might not be provided by one SBR firing alone. Each of these SBRs will produce 615 pound-seconds of action time impulse and have a nominal action time of 0.25 second. The net thrust centerline of both SBRs is directly forward and is slightly below the nominal system cg. at an angle of forty degrees forward of the catapult centerline. Each SBR has separate and redundant ignition ports feeding separate and redundant pressure fired percussion primers which are pressurized by the separate and redundant pressure ports of the Mark 19 Mod 0 catapult.

2.1.2.2.2.2 ACES-II Ejection Seat. The CKU-5/A ROCAT used in the ACES-II seat provides both the catapult and the sustainer rocket subsystems in a single unit. There are some perceived advantages to be gained from combining the catapult and sustainer rocket into a single unit. One of these advantages is the elimination of all the intermediate functions between catapult pressure output and sustainer rocket ignition since the catapult gasses are ported directly to the rocket propellant grain within the unit itself. Another is the weight saving which is assumed to be realized. However, both the S4S and NACES seats use the catapult outer tubes for their guide rails which off-sets any weight advantage of a ROCAT.

The Sustainer rocket section of the CKU-5/A ROCAT is rated at 1150 pound-seconds total impulse and has an effective nozzle angle of fifty-four degrees off the motor case centerline. The STAPAC rocket motor produces an additional upward impulse which then means that the total system sustainer impulse is over 1400 pound-seconds.

2.1.2.2.2.3 ACES-II PLUS Ejection Seat. The ACES-II PLUS seat uses the same rocket catapult as the ACES-II seat with the added capability of gyro control of the motor lateral thrust angle during sustainer rocket firing to provide yaw stabilization of the seat. This is an important improvement in the ACES-II PLUS seat yaw stabilization capability which should reduce the lateral Gy accelerations acting upon the ejectee in those high speed ejections where the stabilizing moments are sufficient to prevent severe seat yawing before the drogue becomes active.

2.1.2.2.2.4 NACES Ejection Seat. The NACES seat uses the Martin-Baker MBEU-147462 or -147463 seat pan rocket motor. This motor is located beneath the seat bucket and has five nozzles, four of which are located near the sides of the seat and provide the upward and forward impulse to the ejected seat. The fifth nozzle is fed by a separate propellant charge which has a shorter action time and provides a clockwise or a counter-clockwise rotation to the seat so as to displace the seat to the right or to the left for side-to-side lateral divergence. The total impulse of this sustainer rocket motor is in the order of 1200 pound-seconds with an action time of about 0.25 second. Although the total seat weight is appreciably heavier than either the S4S seat or the ACES-II seat, the trajectory height provided by this rocket motor impulse and the catapult separation velocity apparently have been sufficient for the recovery parachute to reach full inflation in testing up to 600 KEAS.

The initiation path of the under seat rocket motor is as follows: As the NACES seat moves up the catapult guide rails, redundant lanyards are pulled from their stowage on the seat. Upon reaching full extension these lanyards pull the sear pins from two start switch assemblies. Extraction of these sear pins then allows the firing pin mechanisms to fire two initiator cartridges. Gas pressure from these two initiators is directed to one manifold (tee) and from there one line carries it via a disconnect to the underseat motor igniter cartridge and ignites the underseat rocket motor.

2.1.2.2.2.5 Sustainer Rocket Comparison. Table II compares the three sustainer rockets to pertinent MIL-S-9479B paragraphs. The S4S, the ACES-II and the NACES sustainer rocket systems will provide about the same total impulse levels to an ejectee. The S4S and the ACES-II sustainer rockets seem to have a slight advantage over the NACES sustainer rocket as their thrust vector is directed in a more forward direction relative to the catapult centerline.

The S4S and NACES seat buckets move up and down relative to the primary seat structure and the components/subassemblies which are mounted thereto. This results in a downward shift of the system cg relative to the sustainer rocket thrust line in these seats when the small pilot adjusts the seat bucket upward. As a result the line from the third percentile dummy cg to the ninety-eighth percentile dummy cg in these seats is appreciably more vertical than it is in the ACES-II. This indicates that the net sustainer rocket thrust vectors should be more vertical in these seats (as they are) than in the ACES-II.

The S4S and the ACES-II sustainer rocket thrust vectors are much more nearly parallel to the line from the third percentile dummy cg to the ninety-eighth percentile dummy cg in these seats. Therefore the most forward/downward cg distance and the most aftward/upward cg distance to the sustainer rocket thrust vector will always be greater in NACES than the corresponding distances in the S4S or the ACES-II. This is very important in those low speed, ground level ejections for pilots representing the extremes of cg excursion, in systems not having low speed pitch stabilization.

The complete separation of the sustainer rockets from the catapult in the S4S and the NACES makes it possible to add the capability of igniting only the catapult in low speed ejection conditions in which roll angles greater than ninety degrees are experienced. The addition of such a capability is possible in the S4S and the NACES which would then appreciably reduce the altitude required for recovery under severe roll angle conditions.

2.1.2.3 Pitch Stabilization Subsystem. Pitch stabilization of third generation ejection seats has taken different forms and the American designed S4S and ACES-II seats both have combined two pitch stabilization techniques to obtain important benefits from seat pitch control over a large part of the total escape airspeed/altitude envelope. All third generation seats incorporate a drogue parachute which acts to stabilize the seat in a face forward attitude in the high speed airstream after it has reached the fully inflated condition. At very low speeds the drogue force levels are so small that its effectiveness is severely limited and its ability to stop pitching rates of the ejected seat is unacceptable.

2.1.2.3.1 S4S Ejection Seat. The S4S incorporates a 39 inch ribless guide surface drogue for high speed pitch stabilization and the DART stabilization system for low speed pitch stabilization. The S4S drogue bridle is a single line attached to the seat via the WORD (wind oriented rocket deployment) motor such that release of the WORD motor for parachute deployment will cause the drogue in any flight speed condition to assist the WORD motor in deployment of the recovery parachute and in higher speed ejections the drogue produces much larger forces than the WORD motor and overrides it. The single line attachment to the seat provides less control of the seat at its desired trim angle than a multi-line bridle does, acting more like a rocking chair than a three or four legged stool. The S4S drogue is deployed during the catapult stroke by the catapult pressure at forty to fifty feet per second into the airstream above the seat at the earliest acceptable time in the ejection sequence.

The system cg envelope of the male pilot population of the fifth through the ninety-fifth percentiles in representative ejection seats was evaluated many years ago and was found to be elliptical in shape and dependant upon the weight, the anthropometry and the type and location of the equipment worn by the test subject. Based upon the data taken in the early nineteen sixties it was estimated that in the S4S seat the major and minor axes of the cg envelope ellipse were 3.25 and 2.0 inches respectively.

The DART development tests were performed during the early nineteen-sixties in the zero airspeed condition with ninety-fifth and fifth percentile male pilot weights and with the cg locations ballasted to be plus or minus one inch above or below their nominal locations perpendicular to the net rocket thrust centerline. The DART stabilization system has demonstrated effective means for controlling the seat pitch rates in ejections at airspeeds from zero up to 300 KEAS. Controlling the pitch rate in a near zero airspeed ejection at an extremely low altitude is necessary for escape trajectory enhancement and for repeatable parachute performance. The S4S has the DART stabilization system (which was qualified for the SIIIS-3 seat). The DART corrects for cg. excursions of plus and minus one inch from the nominal third and ninety-eighth percentile cg. locations. The DART subsystem is currently operational in six aircraft.

Aftward, nose up pitching of the S4S seat during tipoff in a 600 KEAS ejection is not controlled by the DART nor by the drogue. The slipper/catapult guide rail system provides the only resisting moments to the aerodynamic nose up pitching moments so long as both the middle pair of slippers and the top pair of slippers engage the catapult guide rails. The tipoff pitching rate in the S4S has been reduced by moving the middle pair of slippers up close to the top pair of slippers. In the S4S the spacing between these slipper pairs is only seven inches (identical to that of the SIIIS-3). The seat nose up pitching in SIIIS-3 and limited S4S system tests at 600 KEAS was below sixty degrees.

Table II. Subsystem: Propulsion

SUBSYSTEM: PROPULSION

	MIL-S-9479B	S4S	ACES-II	NACES
	CATAPULT			
1.	PARAGRAPH 3.4.11.1 a. DRI $\leq$ 18 WITH s.d. = 1 @ 70°F	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE
	b. DRI $\leq$ 22 WITH s.d. = 1 @ 165°F	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE
	SUSTAINER ROCKET			
1.	PARAGRAPH 3.4.6 PROVIDE TAIL CLEARANCE TO 600 KEAS	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE

2.1.2.3.2 ACES-II Ejection Seat. The ACES-II incorporates a 60 inch Hemisflo ribbon drogue parachute for pitch stabilization at medium to high speeds and the STAPAC gyro controlled vernier rocket for pitch stabilization at low speeds. The ACES-II drogue uses a two leg bridle arranged to have more rigid control of seat yaw and effectively only a single line control of seat pitch. In low airspeed ejections (Mode 1) the sequencer does not deploy the drogue and pitch stabilization is provided wholly by STAPAC. The ACES-II drogue is deployed in all medium to high speed ejections by the sequencer after catapult separation. A ballistically fired slug deploys a 24 inch Hemisflo drogue into the airstream that upon inflation will pull the large Hemisflo drogue out to full line stretch. Upon inflation the large Hemisflo drogue is able to hold the ACES-II seat in the face forward attitude with a slight nose down pitch angle relative to the airstream.

The STAPAC is a mature and proven subsystem of the ACES-II providing pitch stabilization for cg. excursions greater than plus or minus one inch from the nominal third and ninety-eighth percentile cg. locations in low speed, Mode 1 ejections.

Aftward, nose up pitching of the ACES-II seat during tipoff in a 600 KEAS ejection is not controlled by STAPAC nor by the drogue. The roller/guide rail system provides the only resisting moments to the aerodynamic nose up pitching moments so long as both the middle pair and bottom pair of rollers engage the guide rails. The tipoff pitching rate then may be reduced only by having the distance between these two pairs of rollers as small as possible. Since this distance in the ACES-II seat is nine inches and the catapult separation velocity is only 43 feet per second, the time the large nose up tipoff moments are active in a 600 KEAS ejection is seventeen milliseconds. Since this is about forty percent greater than that of the S4S under the same high speed ejection condition a larger nose up pitching rate of this seat will occur. With the later ACES-II drogue inflation (see Figure 5.) the maximum nose up pitch angle which results from these tipoff effects will be greater.

2.1.2.3.3 ACES-II PLUS Ejection Seat. The ACES-II PLUS seat uses the same drogue parachute for its pitch stabilization at medium to high speeds and the same STAPAC gyro-controlled vernier rocket motor for pitch stabilization at low speeds as the ACES-II seat. Thus it is expected that the ACES-II PLUS seat will have essentially the same pitch control inputs from these devices as the ACES-II seat.

The ACES-II PLUS seat uses the same rocket catapult and the same guide rail and roller system as the ACES-II seat. Based on this it is expected that the tipoff rates in high speed ejections will be about the same as for the ACES-II seat. However, the ACES-II PLUS seat has improved the drogue deployment system so as to have the drogue deployed by a mortar similar to the NACES and S4S drogue deployment system. Therefore, it is expected that the ACES-II PLUS maximum nose up pitch angle will be reduced by the faster drogue deployment which will be realized.

2.1.2.3.4 NACES Ejection Seat. The NACES seat incorporates a 1.45 meter (57 inches) ribbon drogue with a three leg bridle which upon inflation in a medium to high speed airstream provides positive yaw and pitch stabilization in a face forward attitude. A mortar deploys the drogue at a very high speed into the airstream above the NACES soon after catapult separation has taken place (80 milliseconds after closure of either of the sequencer start switches). The drogue then reaches first full inflation in an extremely short period of time, faster than either the S4S or the ACES-II drogues (see Figure 5), in the medium to high speed airstreams.

Aftward, nose up pitching of the NACES seat during tipoff in very high speed ejections is not controlled by the drogue and the slippers in the catapult mounted guide rails can only provide resisting moments to the aerodynamic nose up pitching moments so long as both the middle pair and bottom pair of slippers engage the guide rails.

The middle pair of slippers of the NACES seat are located over twenty-three inches above the bottom pair such that there is almost two feet of travel of the bottom pair of slippers in the catapult guide rails subsequent to the time the middle slipper pair leaves the catapult guide rails. After this middle pair of slippers has cleared the guide rails, only the engagement of the catapult inner piston with the catapult outer tube can provide some resistance to these aerodynamic moments C.G./catapult eccentricity. This resistance apparently is much less effective and high nose up pitch rates have been observed in the NACES high speed tests.

2.1.2.3.5 Pitch Stabilization Comparison. Once it has inflated the NACES drogue with its three legged bridle is the most effective third generation ejection seat drogue in medium to high speed ejections for controlling the seat pitch angle and it appears to have the most rapid deployment and inflation.

The two stage deployment of the ACES-II drogue is slower than that of the other third generation escape systems (see Figure 5) and gives more time in very high speed ejections for the seat pitch attitude to reach larger values.

All the third generation ejection seats exhibit excessive nose up pitching resulting from tipoff moments in 600 KEAS ejections.

Both the ACES-II and the S4S have pitch stabilization in the very slow speed ejection regime. The STAPAC stabilization system included in the ACES-II seat is pitch rate sensitive and is an active (or energy producing) device, whereas the DART stabilization system incorporated in the S4S seat is pitch angle sensitive and is a passive (or energy absorbing) device. The DART as a passive device has a clear FMEA advantage.

The STAPAC pitch stabilization system in the ACES-II seat adds upward impulse to that supplied by the sustainer rocket whereas the DART pitch stabilization system subtracts impulse from that supplied by the sustainer rockets (SBRs). Thus STAPAC has an advantage over Dart in that less impulse is required in the sustainer rocket motor to provide the desired total impulse for the system.

2.1.2.4 Yaw Stabilization Subsystem. The open ejection seat is unstable in yaw even when the seat occupant is symmetrical in the Y-Z plane. Any asymmetry of the seat or occupant will only make the system even more yaw unstable.

Yawing of an ejection seat in a high speed ejection will result in very large lateral accelerations on the ejectee and severe sideward forces on the head and limbs of the ejectee all of which are extremely hazardous. In the 600 KEAS airstream a yaw angle greater than twenty-five degrees will result in lateral forces/accelerations exceeding the generally accepted human body physiological limit of fifteen G.

2.1.2.4.1 S4S Ejection Seat. The S4S seat incorporated deployable yaw stabilizing fins of sufficient size to provide at least neutral yaw stability to the ejected seat system with a ninety-eighth percentile male occupant. These yaw stabilization fins are erected and become effective from sixty to eighty milliseconds after catapult separation (see Figure 5). The reduced time which is then available for yaw angle displacements to build up is less than one half that of the fastest drogue deployments observed in test. The limited S4S developmental testing demonstrated the effectiveness of the yaw stabilizing fin concept and indicated there would be further improvement in the yaw stabilization of the seat if larger fins were used. This testing also indicated that these fins could provide yaw stabilization aerodynamically without greatly increasing the drag area of the seat. This is an important consideration as the ejection airspeed increases above 600 KEAS.

The S4S drogue with its single leg bridle, aided by the yaw stabilizing fins, was capable of holding the seat in the desired face forward yaw attitude in the limited testing conducted throughout the airspeed range up to 600 KEAS.

2.1.2.4.2 ACES-II Ejection Seat. The ACES-II seat depends on the Hemisflo drogue with its two legged bridle for yaw stabilization after the drogue reaches full inflation in medium to high speed ejections. In an ejection at low speeds with fast system timing, the drogue is not deployed and the seat is not expected to experience yaw disturbing moments sufficient to produce excessive yaw angles before the recovery parachute opening forces start to act on the ejectee. The ACES-II seat has the slowest drogue deployment and inflation of the third generation systems which have been considered in this evaluation. Thus, the probability is that the ACES-II seat will have had more seat yawing than the other third generation seats in the medium to high speed track tests performed on these systems. Although yaw angle data on all the high speed track tests which have been performed on the ACES-II seat were not available for this analysis, seat yawing well past ninety degrees has been observed for some tests in the 600 KEAS ejection environment.

2.1.2.4.3 ACES-II PLUS Ejection Seat. The ACES-II PLUS seat incorporates a gyro control feature on the sustainer rocket to sense yaw rates and thereby to control yaw rate buildup in high speed

ejections until the drogue with its two legged bridle provides yaw stabilization. Also the ACES-II PLUS seat includes a drogue deployment mortar which appreciably speeds up the deployment and inflation of the drogue in a medium to high speed ejection. Since the rate sensing gyro senses yaw rate and not yaw angle, this system cannot act to hold the ACES-II PLUS seat in the true zero yaw attitude. It will, however, limit the yaw rates which can build up in an ejection at any speed. Thus the addition of the drogue mortar must be considered as an important feature of the ACES-II PLUS seat.

Although data on the ACES-II PLUS seat testing performed to date is not available for this study, the probability is that the seat yawing in the 600 KEAS environment will be appreciably reduced. The gyro control of the sustainer rocket will reduce the yaw rates appreciably over those of the ACES-II seat and the faster drogue deployment will provide less time for these reduced yaw rates to act. Therefore, seat yawing in a 600 KEAS ejection possibly would not exceed, and might not even reach, the critical twenty-five degree yaw angle before the drogue becomes effective.

2.1.2.4.4 NACES Ejection Seat. The NACES seat depends on the 1.5 meter ribbon drogue with its three legged bridle to provide yaw stabilization after it reaches full inflation. The NACES seat test results indicate very early drogue inflation (see Figure 5). However, even with this extremely rapid drogue deployment, in some of the 600 KEAS ejection tests of NACES seat yawing beyond sixty degrees has been observed before the drogue could inflate and act to restore the seat to a near zero yaw attitude in the 600 KEAS airstream. It is believed the explanation for this rapid yawing of this seat is the roll divergence rocket motor which also generates a yaw moment.

2.1.2.4.5 Yaw Stabilization Comparison. Table 2.3 compares the three ejection seats to pertinent MIL-S-9479B paragraphs. Both the NACES and The ACES-II seats experience excessive yawing in the 600 KEAS ejection environment. The yawing observed in 600 KEAS testing of these seats, before the drogue had inflated to provide yaw stability to the seat, not only greatly exceeded the twenty-five degree angle considered to be critical in the 600 KEAS airstream but in some tests also neared or exceeded the ninety degree yaw angle which must be considered the worst possible seat attitude for drogue inflation to take place.

The very limited test data of the S4S indicates that its yaw stabilization fins gave neutral yaw stability to the seat when occupied by the ninety-eighth percentile male pilot which was sufficient to prevent excessive yaw angle build up prior to drogue inflation. Subsequent to drogue inflation the stabilization input of the yaw stabilizing fins and the drogue combined to maintain the seat in a near zero yaw attitude in the airstream.

Although these test showed acceptable yaw stability it has been concluded that the yaw stabilizing fins should be increased in size to have positive yaw stability of the seat when occupied by the largest ejectee.

The ACES-II PLUS seat with the gyro controlled sustainer rocket incorporated is a major improvement over the ACES-II seat. It is believed that it will limit the yaw rates input to the seat by the airstream to a fraction of what they would otherwise be. However, a rate sensing system, such as a gyro, cannot maintain a zero yaw rate nor a fixed zero yaw attitude when there are yaw disturbing moments acting on the seat.

The gyro controlled sustainer rocket system of the ACES-II PLUS seat has the disadvantage that as the airstream dynamic pressure increases and the disturbing yaw moments increase proportionately, the yawing rate needed to offset the sustainer rocket thrust to overcome the yawing moment inputs, will also increase proportionately. The obvious result of this intrinsic characteristic of any rate sensing system is that at the highest airspeeds where any seat yawing would be dangerous, larger yaw rates will occur and larger yaw angles will be reached before the drogue can become active. This will be a major consideration in any system designed for use at 700 KEAS where the drogue cannot be deployed until the seat has decelerated to 600 KEAS or less without exceeding human physiological limits.

The gyro controlled sustainer rocket system of the ACES-II PLUS seat has a definite advantage in that it does not add any drag area to that of the seat. In higher speed ejection seat systems for use at speeds up to 700 KEAS the addition of drag to the seat must be carefully evaluated relative to the maximum deceleration levels which will occur prior to drogue deployment.

Theoretically, the yaw stabilization fins of the S4S have several distinct advantages when incorporated into an ejection seat with sufficient area to provide positive yaw stability to the seat/ejectee system as follows.

(1) The aerodynamic restoring moments are always proportional to the airstream dynamic pressure. Since the disturbing moments of primary interest are also aerodynamic, the restoring moments are always proportional to them such that positive yaw stability will be provided throughout the total speed range if it is provided at any speed.

(2) The yaw stabilizing fins generate a restoring moment that is essentially proportional to their yaw angle relative to the airstream and, therefore, they intrinsically have the capability of maintaining a seat in a near zero yaw attitude in the airstream with a zero yaw rate at all ejection airspeeds and dynamic pressures.

(3) Yaw stabilizing fins are passive and have failure modes which are fewer and less severe than those of an active system.

(4) Yaw stabilizing fins, upon deployment, are effective for the complete seat trajectory thereafter and maintain yaw stability even in the event of a drogue failure.

(5) The yaw stabilizing fins automatically sense the system yaw angle relative to the airstream and do not depend on any other mechanical, electronic or pyrotechnic devices for data inputs or for corrective yaw moment outputs.

The disadvantages of the yaw stabilization fins include the weight penalty (3.4 pounds in the S4S), the need for reliable deployment of both fins and increased maintainability functions.

2.1.2.5 Altitude/Airspeed Sensing System. All the third generation ejection seats have post ejection sequencing systems which depend upon correct sensing of the airspeed and altitude conditions prevailing and rely on seat mounted Kiel type Pitot tubes for this information. Actually the seat mounted Pitot tubes measure the total pressure acting on them and the seat static pressure is measured at points on the seat which are protected from direct impingement by the airstream. Catastrophic recovery parachute failure can occur if erroneous altitude/airspeed data is determined from the static pressure and Pitot tube total pressure measurements. It is noted that this has not been a problem in over 250 ACES-II ejections.

2.1.2.5.1 S4S Ejection Seat. The S4S Kiel type Pitot tubes are permanently located on and near the top of the parachute container/head rest assembly and extend outboard beyond the helmet of the seat occupant. The axes of the Pitot tubes are angled outward approximately thirty degrees to have at least one of the two units reading the total pressure even when the seat has yawed to ninety degrees. Each of the two Pitot tubes is connected to a differential pressure sensing bellows in each of two sequencers for complete redundancy of the dynamic pressure measurement. The two sequencer assemblies are located on the seat back of the S4S behind the seat back wedge for protection from the airstream.

Table III. Subsystem: Stabilization

SUBSYSTEM: STABILIZATION

	MIL-S-9479B	S4S	ACES-II	NACES
	PITCH			
1.	PARAGRAPH 3.4.7.1 COUNTERACT C.G. OFFSETS TO ± 2" TOLERANCE	TESTED TO ± 1" C.G. TOLERANCES	TESTED TO ± 2" C.G. TOLERANCES	UNKNOWN TEST CONDITIONS
	YAW AND PITCH			
1.	PARAGRAPH 3.4.7 COUNTERACT AERO FORCES TO HOLD SEAT ≤ 20 DEGREES IN YAW AND PITCH	TIPOFF PITCH TO 45 DEG. @ 600 KEAS, YAW < 20 DEGREES @ 600 KEAS	TIPOFF PITCH TO 60 DEG. @ 600 KEAS, YAW > 90 DEGREES @ 600 KEAS	TIPOFF PITCH > 90 DEG. @ 600 KEAS, YAW > 80 DEGREES @ 600 KEAS

2.1.2.5.2 ACES-II Ejection Seat. The ACES-II Kiel type Pitot tubes are mounted to the sides of the recovery parachute container in a location similar to that of the S4S and each connect to one of two compound bellows mounted in the environmental sensing assembly which is located in a recess on the back side of the seat bucket structure. This location is unique to the ACES-II seat and was chosen to measure the static pressure on the back of the seat. In this location the vacuum which is formed on the back of the seat acts to represent a higher altitude than actual which increases with increasing airspeed. Combining this reduced static pressure with the total pressure from the Kiel type Pitot tube provides a Mode 1 or Mode 2 to Mode 3 cross over curve which starts at an altitude of fifteen thousand feet at zero airspeed and slowly decreases at first with increasing airspeed and then more rapidly as the airspeed increases above 150 KEAS to sea level at about 650 KEAS. This mode crossover curve with descending altitude with increasing airspeed allows the use of a shorter time delay in Mode 2 conditions since the time delay will not be initiated at higher altitudes until the airspeed of the seat has decayed to a value correspondingly lower than 600 KEAS.

Since the Kiel type Pitot tubes are mounted to the recovery parachute container which is projected off the seat for parachute deployment, these Pitot tubes are moved away from the ejectee before he/she is separated from the seat by the parachute opening forces.

2.1.2.5.3 ACES-II PLUS Ejection Seat. The ACES-II PLUS seat has the same Kiel type Pitot tubes for total pressure measurement as the ACES-II seat and provide the same pressure measurements for post ejection system operation. The ACES-II PLUS incorporates a microprocessor type sequencer which has a more advanced technology for post ejection sequencing than the ACES-II seat.

2.1.2.5.4 NACES Ejection Seat. The NACES seat incorporates seat mounted pressure sensors for multimode sequencing. The Kiel type Pitot tubes are mounted on the ends of nine inch long arms initially positioned up alongside the main beams which upon ejection rotate forty-five degrees outward into position for total pressure sensing. In their stowed position these Kiel type Pitot tube sensors fit into a recess behind the main parachute assembly for protection from contamination or damage and in their deployed position they are over twelve inches outboard from the seat centerline and are somewhat further out into the clean air than those of the S4S or ACES-II seats. The NACES static pressure sensors tap the pressure inside the main beams which is well protected from the airstream until the seat pitches over seventy degrees nose up from its initial orientation in the aircraft cockpit.

2.1.2.5.5 Altitude/Airspeed Sensing System Comparison. Each of the third generation ejection seats appear to have their total and static pressure sensors correctly designed for the functions they are to perform during the escape sequence and the differences between them are slight.

The NACES seat stowage and deployment subsequent to firing of the catapult of the Pitot head assemblies provides two definite advantages. Firstly, in their stowed position the Kiel type Pitot tubes are protected from damage or contamination by foreign objects, and secondly, in their deployed position, which is independent of the aircraft canopy configuration, they can be further outboard into the airstream.

The ACES-II, the ACES-II PLUS and the NACES seats sense the airspeed and altitude conditions very quickly after separation of the seat from the guide rails before severe pitch and/or yaw angles can build up in a high speed ejection. Therefore, good seat attitude can be assured at the time the total and static pressure measurements are made which is advantageous. However, in this close proximity to the aircraft the disturbed air flow over the aircraft with its now open cockpit will not represent the true free stream conditions even in subsonic ejections and in supersonic ejections the shock wave forward of the seat will produce higher static pressures and lower dynamic pressures than the free stream conditions which can be catastrophic.

The S4S seat senses the airspeed and altitude conditions continuously until the airspeed has decayed to a value safe for the parachute to be deployed. Based on limited development testing, this seat only needs to sense that the airspeed and/or altitude is greater or less than the maximum airspeed and/or altitude at which it is safe to deploy the parachute for recovery. Therefore, it is not necessary that the airspeed be accurately sensed throughout the total airspeed range but only in the range of 275 to 325 KEAS and as a result it will be found that even in supersonic ejections the conditions behind the shock wave ahead of the seat will indicate airspeeds above the safe parachute deployment airspeed and no premature parachute deployment will occur. However, with continuous sensing of the altitude and

airspeed it is necessary that the seat yaw and pitch never take the seat beyond the limiting angles at which the maximum safe airspeed for parachute deployment can be accurately measured.

2.1.2.6 Post Ejection Sequencer. The third generation escape systems are characterized by multimode post ejection sequencers which have tremendously speeded up the recovery parachute timing for the low speed, low altitude mode while maintaining the high speed or high altitude performance of the system. These sequencers have eliminated the pyrotechnic time delays and are either electronically or microprocessor controlled. They are also characterized by positive deployment of the recovery parachute using a rocket, a mortar or a rocket and drogue in combination rather than depending on a pilot chute for this function.

2.1.2.6.1 S4S Ejection Seat. The S4S has a two mode sequencer that has only the function of providing recovery parachute deployment at the earliest possible time at which it is safe to do so. The two sequencing modes of the S4S sequencer include the following.

- Low Altitude and Low Speed
- Low Altitude/High Speed and High Altitude/any speed

The low altitude, low speed mode envelope extends from sea level up to fifteen thousand feet (pressure altitude) and from zero to three hundred KEAS. The low altitude/high speed and high altitude mode envelope extends from three hundred to six hundred KEAS at low altitudes and encompasses all airspeeds at altitudes above fifteen thousand feet at which the pilot is equipped to safely eject in the open seat and the aircraft has flight capability. The time delay in the low altitude, low speed mode is just over fifty milliseconds after catapult separation such that recovery parachute deployment in the downstream direction is aided by the forward and upward thrusting of the sustainer rockets. The time delay in the low altitude/high speed and high altitude/any speed mode is entirely variable and is determined by the actual time required to decelerate to 300 KEAS for the conditions existing at the time of ejection or to fall to an altitude of fifteen thousand feet. Thus the time delay in an ejection at low altitude at an airspeed of 325 KEAS is only slightly longer than the shortest timing of fifty milliseconds, while that for an ejection at the same altitude at an airspeed of 600 KEAS is much longer, but only long enough to have the seat/ejectee decelerate to the 300 KEAS airspeed. Likewise, the time delay in a high altitude ejection is determined by the actual time required to descend to an altitude of fifteen thousand feet (pressure altitude).

The S4S has two separate and fully redundant sequencers, each of which is a completely self contained unit. Each of these two sequencer units has its own thermal battery power supply, a static pressure bellows and two dynamic pressure bellows. One of the two dynamic pressure bellows is connected to the right hand Pitot tube and the other is connected to the left hand Pitot tube such that if either of them senses an airspeed greater than 300 KEAS the circuit to the electrically fired initiator is opened.

The combination of the airspeed being less than 300 KEAS and the pressure altitude being less than 15,000 feet, which are the only requirements for parachute operation, gives Mach number immunity for all airspeeds up to 700 KEAS at all altitudes up to 42,000 feet. This performance rests on the fact that even with the worst case of normal shock waves forward of the seat and forward of the Pitot tubes the sensed dynamic pressure will always be greater than that which is equivalent to 300 KEAS at sensed pressure altitudes below 15,000 feet until the true altitude is about 45,000 feet (see Figure 2 which is Figure B-1 in Appendix B of LME Report ALSEE 98321-90-03, Escape System Sequencing Subsystem Study). For oblique shock waves the maximum safe altitude with Mach number immunity is even higher.

2.1.2.6.2 ACES-II Ejection Seat. The ACES-II post ejection sequencer is responsible for the timing and initiation of six subsystem events. These six subsystem events are as follows.

- Drogue parachute deployment
- STAPAC ignition
- Divergence rocket ignition
- Recovery parachute deployment
- Drogue bridle disconnection

• Harness and lap belt release

These events are controlled and timed during an ejection based on the sensed environmental conditions which were determined near the end of the catapult stroke.

In the low speed, low altitude Mode 1 condition the recovery parachute is deployed just one hundred twenty milliseconds after the sequencer start switch is closed. In the low altitude, high speed Mode 2 condition the recovery parachute is deployed 850 milliseconds after the sequencer start switch is closed and in the high altitude Mode 3 condition the sequencer will wait until the ejected seat decelerates and/or falls into the Mode 2 condition at which point the one second delay time will take over.

Therefore the ACES-II sequencer introduces the one 0.85 second time delay for recovery parachute deployment even for those medium speed ejections from 250 KEAS to 450 KEAS for which a shorter time delay would be sufficient. When it is realized that a large portion of the total ACES -II ejection population has taken place within this airspeed range the disadvantage of having one fixed time delay active over such a large airspeed range becomes evident.

The ACES-II sequencer is not Mach number immune. Ejection in the ACES-II ejection seat at 600 KEAS at altitudes above 15,000 feet can cause the environmental sensor to sense a Mode 2 condition when the actual condition is Mode 3. The effect of the worst case of normal shock waves forward of the seat and the Pitot tubes is graphed for altitudes from 18,000 feet up to 48,000 feet in Figure 3 (Figure D-1. in Appendix D of LME Report ALSEE 98321-90-03).

90° SEAT & 90° PITOT SHOCK WAVE ANGLE

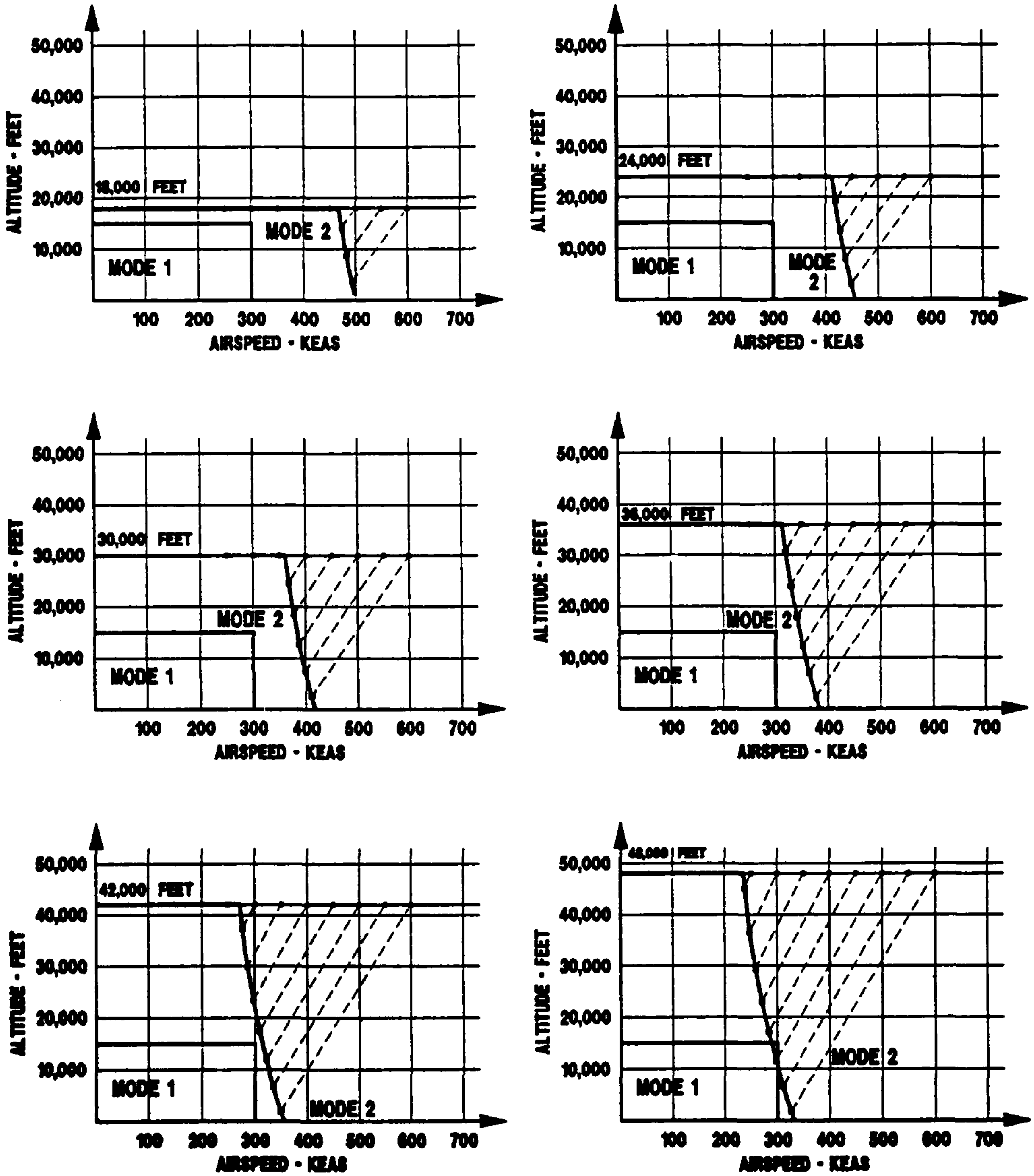


Figure 2
S4S Normal Shock Wave Effects

90° SEAT & 90° PITOT SHOCK WAVE ANGLE

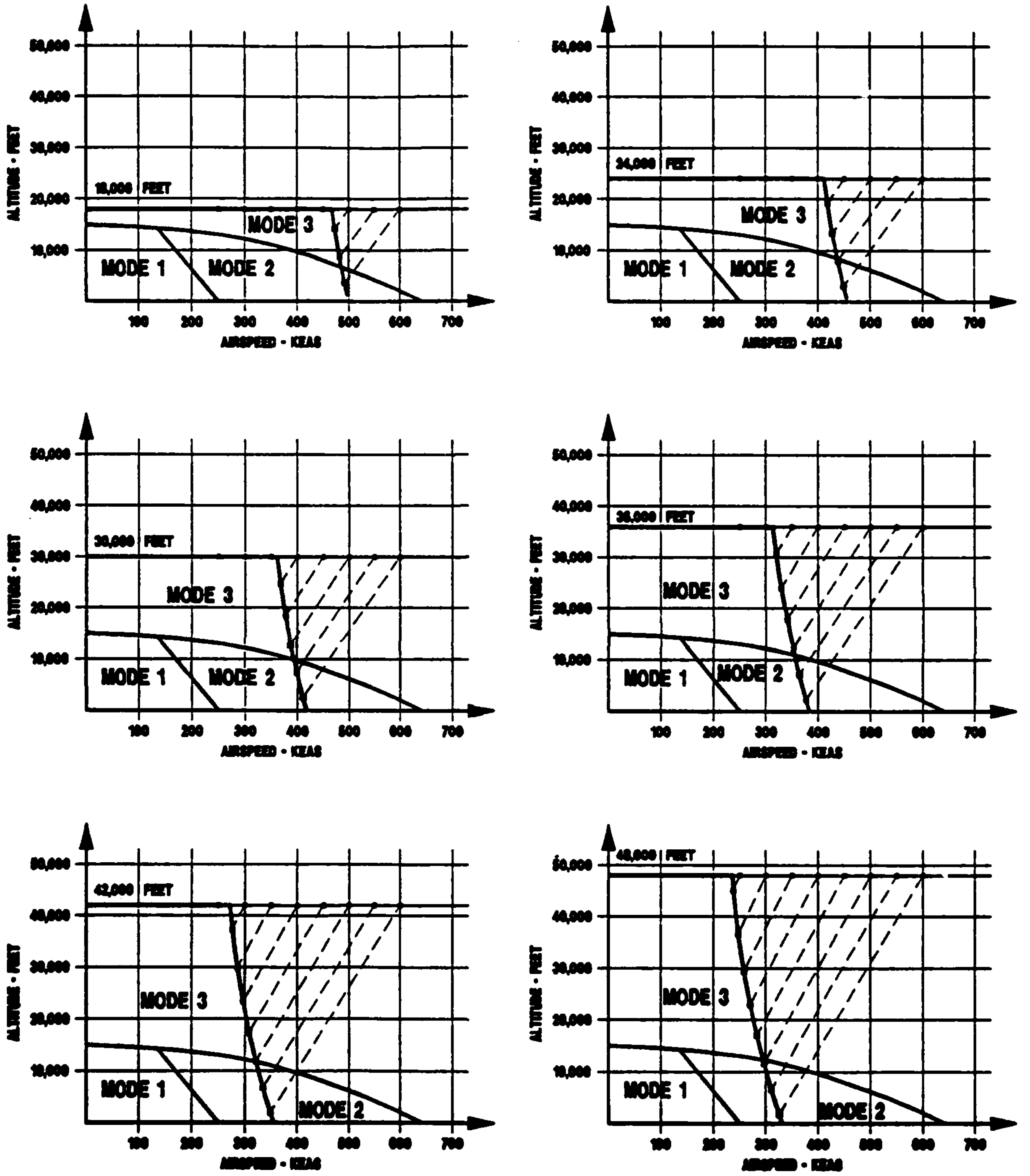


Figure 3
ACES-II Normal Shock Wave Effects

Since the ACES-II seat would decelerate to an airspeed well below 500 KEAS in a 600 KEAS ejection during the 0.85 second Mode 2 time delay, the ACES -II sequencer can be made positively immune to those shock wave induced static and total pressures which do indicate Mode 2 conditions to the environmental sensor. This capability can be provided by the simple means of having the sequencer stop the 0.85 second Mode 2 time delay whenever Mode 3 conditions are subsequently sensed and reset it to 0.85 second when the Mode 3 to Mode 2 crossover does occur later.

2.1.2.6.3 ACES-II PLUS Ejection Seat. The microprocessor based Advance Recovery Sequencer (ARS) is considered to be a very important feature of the ACES-II PLUS ejection seat. This unit was completely described in the 1988 SAFE Symposium Proceedings and will only be summarily described here.

The ARS has the capability of variable Mode 2 timing with the time delay set by the static and total pressure measurements and it has automatic time delay function cutoff when Mach 0.8 or greater conditions are sensed. The ARS uses solid state pressure transducers with superior accuracy due to their greater sensitivity and to software characterization of each individual transducer. It is believed that all the functions of the ACES-II analog sequencer are provided by the ARS with greater precision, with better reliability, with built-in-test (BIT) capability, with less maintenance, with longer life and with lower life cycle costs.

The use of the variable Mode 2 time delay based only upon the static and total pressure measurements made in close proximity to the aircraft will be the source of less than ideal time delay values being chosen in some Mode 2 ejections. This subject has been cursorily discussed previously in Section 2.1.2.5 and is considered in more detail in Appendix C.

The use of Mach 0.8 as the cutoff Mach number appears to be too high a value. The Mach number behind a normal shock wave will be in the order of the inverse of the free stream Mach number. Thus it would be expected that free stream Mach numbers of 1.3 or greater can result in a seat measured Mach number less than 0.8 and 600 KEAS ejections at altitudes of 18,000 feet or above may well be unsafe. Since a 0.5 Mach condition at altitudes below 15,000 feet is above the Mode 1 to Mode 2 crossover line it appears that the ARS could be made totally Mach number immune by lowering the cutoff Mach number to this value and in addition by having it reset the time delay whenever a Mode 3 or Mode 4 condition is sensed.

There has been strong disagreement voiced to these conclusions. In light of this it is strongly recommended that wind tunnel tests of a seat in a near zero yaw and pitch attitude be performed at Machs from 1.0 through 2.0. Such tests can settle this matter beyond doubt.

2.1.2.6.4 NACES Ejection Seat. The NACES post ejection sequencer is responsible for the timing and initiation of five subsystem events. These five subsystem events are as follows.

- Drogue deployment catapult initiation
- Recovery parachute deployment rocket ignition
- Lower drogue bridle release
- Upper drogue bridle release
- Harness release

These events are controlled and timed during an ejection based on the sensed environmental conditions which were determined near the end of the catapult stroke. In the low altitude, low speed Mode 1 condition (0 - 8000 feet, 0 - 300 KEAS) the sequencer will ignite the recovery parachute deployment rocket motor one hundred seventy milliseconds after either one of the two start switches are closed. In the low altitude, medium to high speed Mode 2 condition (0 - 8000 feet, 300 - 500 KEAS) the sequencer will ignite the recovery parachute deployment rocket motor 0.92 second after either one of the two start switches is closed. In the low altitude, high airspeed Mode 3 condition (0 - 8000 feet, 500 - 600 KEAS) the sequencer will ignite the recovery parachute deployment rocket motor 1.12 second after either one of the two start switches is closed. In the medium altitude Mode 4 condition (8000 - 18,000 feet, 0 - 600 KEAS) the sequencer will ignite the recovery parachute deployment rocket motor 2.72 seconds after either one of the two start switches is closed and in the high altitude Mode 5 condition (above 18,000 feet, 0 - 600 KEAS) the sequencer will wait until the ejected seat falls to an altitude of

18,000 feet at which time the sequencer provides a seventy millisecond delay time for the recovery parachute deployment rocket motor ignition.

The NACES sequencer is not Mach number immune. In any 550 KEAS or higher airspeed ejection of NACES in the medium altitude Mode 4 condition the Mach number will be greater than one and the static and total pressures behind the shock wave acting on the seat mounted sensors will put the sequencer into its Mode 3 timing with its much shorter time delay for the deployment of the recovery parachute. In a 500 KEAS or higher airspeed ejection of NACES at any altitude above 18,000 feet the shock wave forward of the seat will generate static and total pressures equivalent to a Mode 4 or a Mode 2 ejection condition with deployment of the recovery parachute occurring after a fixed time delay at very high airspeeds and near the original flight altitude at the time of ejection. The effect on NACES for the worst case of normal shock waves forward of the seat and Pitot tubes is depicted in Figure 4 for altitudes from 18,000 feet up to 48,000 feet (Figure E-1. in Appendix E of LME Report ALSEE 98321-90-03).

As was true for the ACES-II sequencer the fixed time delay greater than one second in a sensed Mode 2, Mode 3 or Mode 4 ejection condition assures that the ejected seat in any 600 KEAS ejection will decelerate well below 500 KEAS before the time delay has elapsed. Since this is true, the NACES sequencer can be made Mach number immune by having the sequencer stop the set time delay whenever any higher mode conditions are being sensed and resetting the time delay for deployment of the recovery parachute to the higher mode. It will be important that this capability hold not only for switching from Mode 2 to Mode 4 but also for switching from Mode 4 to Mode 5 subsequently.

2.1.2.6.5 Post Ejection Sequencer Comparison. Table IV compares each ejection seat sequencer to pertinent MIL-S-9479B paragraphs. The major contribution of the post ejection sequencer to the recovery performance of an escape system is its timing of the recovery parachute deployment at the earliest acceptable time. In this respect the fixed time delays of the ACES-II low altitude, high speed Mode 2 timing, of the NACES low altitude, medium and high speed Modes 2 and 3 timing and of the NACES medium altitude Mode 4 timing are much less capable than the variable timing of the S4S low altitude/high speed and high altitude/any speed Mode 2 and of the ACES-II PLUS low altitude, high speed Mode 2 variable timing.

Initiation of the two separate and redundant S4S sequencers is by means of two separate and redundant gas pressure tubes that are connected to the two sections of the dual tube catapult. Initiation of the two NACES redundant sequencers is by means of two separate and redundant cables. Initiation of the ACES-II sequencer is by means of a single gas pressure hose which must be disconnected to remove the seat from the aircraft. This represents a catastrophic single point failure in the ACES-II which cannot be one time inspected upon seat assembly since it must be reconnected whenever the seat is replaced in the aircraft cockpit after removal. Since the ACES-II PLUS sequencer (ARS) directly replaces the ACES-II analog sequencer without any known seat modifications it is concluded that this same single point failure also exists in the ACES-II PLUS seat. It appears that a separate gas pressure path from one of the two gas pressure sources which initiate the ACES-II escape system could be introduced on the seat to provide a separate and redundant means for initiation of the sequencer which would not be disconnected when the seat is removed from the aircraft.

90° SEAT & 90° PITOT ANGLE

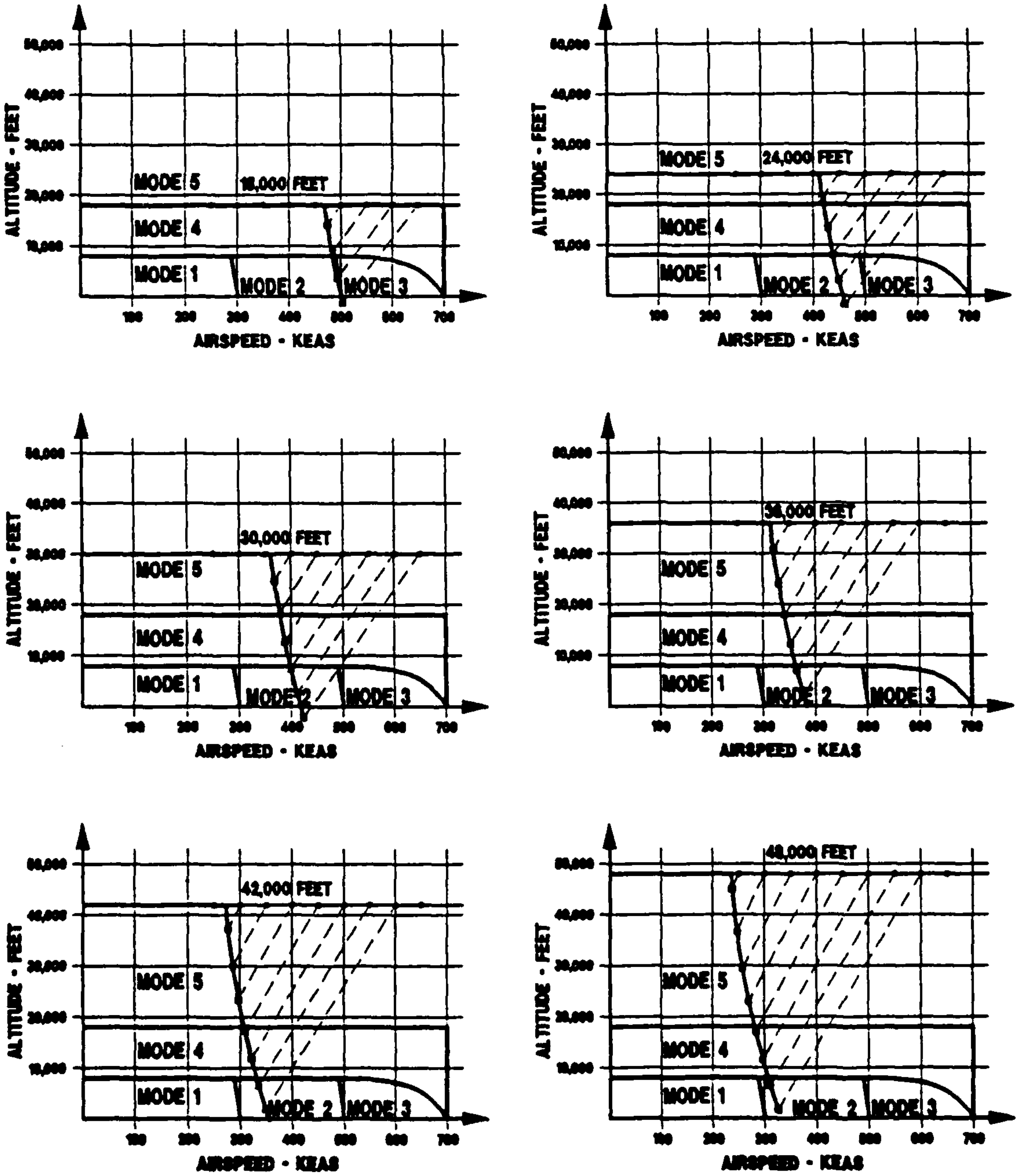


Figure 4
NACES Normal Shock Wave Effects

The S4S sequencer provides protection from supersonic shock waves for airspeeds up to 700 KEAS at all altitudes up to over 40,000 feet. The ACES-II analog sequencer provides protection from supersonic shock waves up to about 550 KEAS at 18,000 feet pressure altitude and up to about 490 KEAS at 48,000 feet pressure altitude with essentially a linear decrease in the maximum safe ejection airspeed between these airspeed values at the intervening altitudes. The ACES-II PLUS ARS provides protection from supersonic shock waves up to an airspeed equivalent to Mach 1.25 at any altitude but is not protected by the 0.8 Mach number cutoff at higher Mach numbers. Thus its performance is essentially the same as that of the ACES-II analog sequencer at Mach numbers above 1.25.

2.1.2.7 Main Recovery Parachute Subsystem (MRP). The main recovery parachute subsystem performance holds the key to total escape system performance. Therefore it is significant that the third generation escape systems have different main recovery parachute subsystems. The main recovery parachute subsystems will be evaluated in two phases. The first phase will be the evaluation of the deployment means used to deploy the parachute canopy into the airstream and the second phase will be the evaluation of the canopy development or filling process.

The limited parachute data provided to LME on parachute performance did not include line stretch loads versus parachute opening shock loads. Since all the third generation seats considered in this study use parachutes with lines-first deployment, it is believed that the line stretch (snatch) loads will be less than the later opening shock loads in all cases.

2.1.2.7.1 Main Recovery Parachute Deployment Subsystem

2.1.2.7.1.1 S4S Ejection Seat. The S4S main recovery parachute deployment is by means of the WORD (Wind Oriented Rocket Deployment) motor in cooperation with the S4S drogue. In very low speed ejections the WORD motor will provide the primary deployment energy to the main recovery parachute (MRP) since it is a constant force device whereas the drogue provides a variable force which is proportional to the airstream dynamic pressure. In medium to high speed ejections the drogue will provide the primary deployment energy to the MRP since its force input will be appreciably greater than that of the WORD motor.

In very low speed ejections the WORD motor is oriented in a direction opposite to the sustainer rocket thrust by its inertia. Then upon its release from the seat back the forward/upward acceleration of the seat will act so as to accelerate it backward/downward away from the seat. Upon its firing the WORD motor will deploy the MRP downward and backward in the desired direction for the fastest possible deployment to the downstream line stretch condition. It is very important that the MRP headrest container opens to the rear such that the mass of the MRP in its deployment bag has a downstream deployment force of as much as 150 pounds acting on it as a result of the forward acceleration of the S4S seat during the sustainer rocket motor action time. This added to the WORD motor force of about 180 pounds will produce a deployment velocity of as much as 100 feet per second with only 55 pound-seconds impulse produced by the WORD motor. Also it is important that upon reaching line stretch the parachute canopy is ready for its development to take place immediately.

At flight speeds of 100 KEAS and above in the low altitude, low speed Mode 1 regime the drogue will inflate sufficiently to provide some deployment force in addition to that of the WORD motor. At lower airspeeds the drogue will only act as a backup in the event the WORD motor fails to fire since its inflation can be after the WORD motor has completed the MRP deployment. In the event of a drogue failure at the higher airspeeds such that the drogue bridle forces are sufficient to fire the WORD motor, MRP deployment would be provided by the WORD motor but at a slightly later time.

Table IV. Airspeed/Altitude Sensing and Sequencing (Normal Shock Waves Assumed)

AIRSPEED/ALTITUDE SENSING AND SEQUENCING
(NORMAL SHOCK WAVES ASSUMED)

	MIL-S-9479B	S4S	ACES-II	NACES
1.	PARAGRAPH 3.4.8 ALTITUDE SETTING 15K ± 1K FEET MULTIMODE SENSING VELOCITY, FORCE OR ACCELERATION	15K ± 1K FEET TWO-MODE AIRSPEED AND ALTITUDE SENSING	15K ± 1K FEET TRIMODE-AIRSPEED AND ALTITUDE SENSING	18K ± ? FEET FIVE MODE- AIRSPEED AND ALTITUDE SENSING
2.	PARAGRAPH 3.4.10 FIRST FULL INFLATION AT LOW ALTITUDE <=3.0 SECONDS	3.8 SEC @ 0 KEAS <=2.7 SEC UP TO 600 KEAS	2.4 TO 5.3 SEC @ 0 KEAS <=2.1 SEC @ 100 TO 250 KEAS <=3.4 SEC UP TO 600 KEAS	3.5 TO 5.8 SEC @ 0 KEAS <=5.3 SEC @ 80 TO 250 KEAS <=3.6 SEC @ 300 TO 500 KEAS <=3.0 SEC @ 550 TO 600 KEAS
3.	PARAGRAPH 3.4.12 AIRCRAFT AIRSPEED/ ALTITUDE ENVELOPE OR 600 KEAS	600 KEAS UP TO 40K FEET*	600 KEAS UP TO 15K FEET* 550 KEAS UP TO 23K FEET* 500 KEAS UP TO 42K FEET*	600 KEAS UP TO 8K FEET* 500 KEAS UP TO 18K FEET* 450 KEAS UP TO 30K FEET*

* CALCULATED ASSUMING NORMAL SHOCK WAVES

2.1.2.7.1.2 ACES-II Ejection Seat. The ACES-II main recovery parachute deployment is by means of a mortar in cooperation with a small pilot chute. In very low speed ejections the mortar provides the total deployment energy to the main recovery parachute (MRP) since the pilot chute provides a variable force which is proportional to the dynamic pressure of the airstream and will be acting in a direction to slow the deployment velocity generated by the mortar. In the high speed Mode 2 regime the mortar will put a cross stream velocity into the MRP and the pilot chute will generate a large downstream force which will move the MRP in the downstream direction. With the pilot chute attached to the top of the MRP deployment bag it will also rotate it into the desired downstream orientation.

Cross stream deployment of the C-9 parachute canopy creates some problems at high speed. Partial inversions and/or lineovers have been observed in high speed tests of the cross stream deployed C-9 as a result of the airstream catching the upwind panels and causing them to try to move downstream through the downwind suspension lines. This can result in different parachute inflation problems with extensive canopy damage and long inflation times. A reefing line with time delayed line cutters was added to the ACES-II MRP to eliminate these problems. The time delay for the line cutters was chosen to have disreef occur after line stretch in airstreams above 200 KEAS and to have it occur before line stretch in lower speed airstreams.

In the low altitude, low speed Mode 1 regime the ACES-II MRP is mortar deployed prior to sustainer rocket burnout and the upward seat acceleration component generates a downward force on the MRP mass which will oppose the upward mortar deployment. Since the mortar generates much higher forces than these opposing inertial forces the deployment velocity of the MRP is only slightly affected. However, this upward deployment of the MRP introduces an undesirable delay in the time required to reach the downstream line stretch condition in very low speed ejections. Since the ACES-II seat velocity in very low speed ejections will have an upward and forward airspeed vector, the upward deployment of the MRP requires that the seat overtake and pass it in this upward direction before it can reach the downstream linestretch condition for development. This can add one-half second to the total inflation time of this parachute in near zero speed ejections.

To assure that the MRP cannot get involved with the drogue, the drogue is not deployed in the low altitude, low speed Mode 1 regime and the drogue is released from the seat at the time of MRP deployment in the low altitude, high speed Mode 2 regime.

2.1.2.7.1.3 ACES-II PLUS Ejection Seat. The ACES-II PLUS main recovery parachute deployment is the same as the ACES-II deployment. Therefore the preceding evaluation is applicable to the ACES-II PLUS seat also.

2.1.2.7.1.4 NACES Ejection Seat. The NACES main recovery parachute deployment is accomplished by means of the parachute deployment rocket motor (PDRM). This PDRM is initially projected upward off the NACES seat parallel to the seat back. This means that in a high speed ejection the MRP is initially deployed in a cross stream direction and in a very low speed ejection the MRP is initially deployed with an upstream airspeed component similar to the ACES-II MRP deployment. However, at flight speeds the PDRM rotates into the head first orientation in the airstream such that it acts to deploy the MRP in an upwind direction. Two physical phenomena join together to produce this head first reorientation of the PDRM even in ejections at low flight speeds.

The location of the heavy PDRM nozzles at the head end of the motor moves the motor cg forward of the center-of-pressure such that the motor body will be stable in a head first attitude in the airstream. Also the attachment of the parachute extraction line to the tail end of the PDRM applies a downstream force at that point to the PDRM which also acts to turn it into a head first attitude in the airstream.

2.1.2.7.1.5 Main Recovery Parachute Deployment Subsystem Comparison. In the low speed, low altitude Mode 1 ejection regime the downstream deployment provided by the inertia WORD feature of the S4S will result in a time saving of over one-half second and as much as one second to downstream line stretch as compared to the other third generation escape systems.

The ACES-II and ACES-II PLUS deployment mortar/pilot chute deployment of the MRP results in a cross/down wind deployment which dictates the incorporation of a reefing line in the C-9 canopy. The reefing line and its time delayed cutters increase both the cost and complexity of the recovery parachute system while reducing its total reliability.

The NACES PDRM deployment of the MRP results in its cross/up wind deployment which in turn results in the longest time for deployment to downstream line stretch.

2.1.2.7.2 Main Recovery Parachute Development

2.1.2.7.2.1 S4S Ejection Seat. The S4S recovery parachute is the Automatic Inflation Modulated (AIM) parachute manufactured by Irvin Industries Canada, Ltd. This parachute requires directly downstream deployment if its high speed development capability with automatic inflation modulation is to be truly effective. In the S4S seat which does provide directly downstream deployment, this parachute has a 300 KEAS maximum deployment airspeed in the Mode 1 condition.

At low speeds the AIM parachute has a slower development time than the C-9 canopy to first full inflation but it has much less variableness in its development time at a given airspeed and also has appreciably less over inflation with a shorter time period from first full inflation to final inflation than the C-9 canopy. The Webb chute in the mouth of the AIM canopy is an important feature of this parachute because it provides an initial canopy mouth opening which is more rapid and repeatable at all airspeeds. The time to first full inflation of the AIM parachute as observed in six S4S system tests at airspeeds up to 600 KEAS is plotted in Figure 6 in Section 2.1.3. The variation in the development time of the AIM parachute is not evident here due to the very limited number of tests performed. In the vertical descent configuration the AIM parachute has an oscillation angle of up to fifteen degrees which is appreciably less than that of the C-9 canopy. In the forward drive configuration it has a slightly smaller oscillation angle in the order of thirteen degrees.

With a suspended weight of 300 pounds the 29.6 foot AIM parachute used in the S4S seat has a vertical descent rate equivalent to 24 feet per second or less at a pressure altitude of five thousand feet.

2.1.2.7.2.2 ACES-II Ejection Seat. The modified C-9 canopy used in the ACES-II seat has been strengthened in the upper crown area and has had reefing rings added to its skirt at each suspension line. It is believed that the reefing line was added to the C-9 canopy to limit the effects of the cross stream deployment on the canopy development process, and thus to reduce the opening shock loads in any high speed deployment condition. It is also believed that the strengthening of the canopy crown area was needed since the canopy apex vent will not always be in line with the canopy mouth at downstream line stretch with cross stream deployment. When the canopy apex vent and canopy mouth are not aligned in a high speed parachute deployment, the initial inrush of air into the canopy will not be able to exit through the vent and thus it will impinge on the crown area canopy material with severe localized and asymmetrical loading of the downstream portions of this crown area.

In a low speed ACES-II ejection the C-9 canopy will achieve downstream line stretch after the reefing line cutters have functioned and have cut the reefing line. Thus development to first full inflation of this canopy should be unhindered in such low speed ejections and the time required to reach this condition as measured from downstream line stretch should be the same as that for an unmodified C-9 canopy. In a high speed ejection the ACES-II C-9 canopy will reach downstream line stretch some time before the reefing line cutters function and thus the development time from downstream line stretch to first full inflation for this canopy will be longer than that for an unmodified C-9 canopy.

In Figure 6 in Section 2.1.3 the time to first full inflation observed in ACES-II system tests at airspeeds up to 630 KEAS are graphed. The ACES-II tests presented in this graph were all performed at altitudes above five thousand feet MSL which probably put the 630 KEAS tests and maybe put the 600 KEAS tests in the Mode 3 condition for a short period of time. This might explain the apparent increase in time to first full inflation in these tests as compared to the other Mode 2 tests shown in this figure. At flight speeds above 150 KEAS in the Mode 1 regime the ACES-II time to first full inflation appears to be quite repeatable but at the zero speed condition it is quite variable with a variation of three seconds in six tests. In theory this time to first full inflation of the ACES-II MRP should decrease with airspeed in the Mode 2 regime from 250 KEAS up to 450 KEAS, therefore it is expected that if more test data were available in this speed range there would be higher values on this graph in the 250 KEAS to 350 KEAS speed range. Also in theory this time to first full inflation of the ACES-II MRP should decrease with airspeed in the Mode 1 regime from zero up to 150 KEAS which did occur in this speed range.

The vertical rate of descent of the 28 foot C-9 canopy with a 300 pound suspended weight would average one to two feet per second more than that of the 29.6 foot AIM canopy although the ACES-II

system tests for which data was available were performed with 98th percentile suspended weights of 275 to 285 pounds.

The C-9 canopy oscillation angle under steady state vertical descent conditions can be as much as twenty-five to thirty degrees. If the four line cut is made to provide some forward drive to this canopy the oscillation angle will be reduced appreciably. Shaped canopies, in general, have reduced oscillation angles as compared to that of the flat solid C-9 canopy.

Theoretically the reliability of development to first full inflation of the ACES-II MRP has been decreased by the addition of the reefing line with its reefing line cutters. The redundancy of the two cutters on the reefing line protects against a single failure point in the inflation of the canopy but it does not protect against premature disreefing in high speed deployments if either time delay column goes too soon.

2.1.2.7.2.3 ACES-II PLUS Ejection Seat. Although the ACES-II PLUS seat has the same parachute system as the ACES-II seat the improved advanced recovery sequencer (ARS), with its variable time delay in the low altitude, high speed Mode 2 regime, will introduce shorter time delays which will result in higher airspeed deployments of the MRP and thus higher speeds at downstream line stretch will be experienced. Since these conditions are within the high speed deployment capability of this parachute system, greatly improved system performance in the 250 KEAS to 450 KEAS speed range will be realized without appreciably increased hazard of injury to the ejectee. With this improvement in the Mode 2 timing it is fully expected that system tests would provide times to first full inflation which would rise from an average of about two seconds at 250 KEAS up to the same data points recorded in the ACES-II system tests at 600 KEAS.

It is expected that all other characteristics such as rate of descent, oscillation angle and development reliability of the ACES-II PLUS MRP will be essentially identical to those of the ACES-II MRP.

2.1.2.7.2.4 NACES Ejection Seat. The NACES MRP is the GQ Type 2000 Aeroconical Parachute. This parachute system includes a 6.2 (recently upgraded to the 6.5) meter aeroconical-type canopy with a 20 degree conical ribbon controller drogue which are deployed from the same deployment sleeve. The recovery parachute canopy is deployed lines first from this deployment sleeve and afterward the controller drogue is also deployed lines first from this sleeve. This canopy does not have any inflation aids as it is a fast opening canopy but does incorporate the controller drogue to slow down the canopy development in the higher airspeed deployment conditions. As noted in Section 2.1.3.7.1.4 above the cross/up wind deployment of the NACES MRP causes the controller drogue to be deployed up wind of the MRP canopy in an apex first attitude such that it cannot be truly effective during the initial development of the MRP canopy but does incorporate the controller drogue to slow down the canopy development in the higher airspeed deployment condition.

The NACES time to first full inflation data taken in the sled tests and in the flight tests which were available for this study are also graphed in Figure 6 in Section 2.1.3. The Mode 3 data at ejection airspeeds of 550 KEAS to 600 KEAS shows a slight decrease in time to first full inflation with increasing airspeed. Likewise in Modes 1 and 2 this decrease in time to first inflation with increasing airspeed at ejection is observed. Also it is noted in this figure that the spread in this time to first inflation data tends to increase as the airspeed at ejection decreases. This is as expected since the upstream deployment of the MRP canopy will be more severe as the airspeed at ejection is decreased.

The GQ Type 2000 Aeroconical canopy demonstrated a vertical rate of descent of twenty-two feet per second with a suspended weight of 291 pounds under standard atmospheric conditions at sea level during its qualification test program (Richards, 1988). This rate of descent is equivalent to a free fall of only 7.5 feet and is considered to be very acceptable for low injury hazard at ground touchdown.

The GQ Type 2000 Aeroconical canopy is expected to have a low oscillation angle in both the vertical descent mode and the forward drive mode.

The reliability of the NACES MRP to reach a fully inflated condition in lower speed downstream line stretch conditions is believed to be equal to or better than that of the standard C-9 canopy. The reliability of the development process of the NACES MRP in the higher speed downstream line stretch conditions is reduced by the stated necessity for the controller drogue to inflate to a larger diameter than the diameter of the canopy mouth upon initiation of its development process (Richards, 1988).

2.1.2.7.2.5 Main Recovery Parachute Development Comparison. Table V compares each ejection seat parachute subsystem to pertinent MIL-S-9479B paragraphs. The major contribution of the main recovery parachute to the recovery performance of an escape system is its timing from initiation of deployment to first full inflation at any deployment airspeed. The three third generation escape systems for which data was available have their time from initiation to first full inflation plotted on a single graph in Figure 6. In this graph it is not possible to evaluate the MRP development time as separate from other system time delays however it is expected that the major source of any large time variation seen at a given ejection airspeed is the deployment time plus the development time (inflation time) of the parachute.

Since there are so few tests of the S4S seat the overall spread of the time to first full inflation of the MRP cannot be truly evaluated but the measured times do indicate that the S4S total recovery system has the fastest operation of the systems evaluated. In the very critical medium speed range from 250 KEAS to 450 KEAS the time saving is appreciable when compared to the recovery times of the ACES-II seat and the NACES seat. The ACES-II seat tests indicate that the time to first full inflation at low flight speeds has less variation than that of the NACES seat. At zero airspeed it has a slightly larger variation but a smaller average time value than that of the NACES seat.

The GQ Type 2000 Aeroconical parachute and the AIM parachute both have slightly superior vertical descent rates as compared to the ACES-II modified C-9 canopy. Since the GQ descent rates were taken to sea level conditions with a 291 pound suspended weight while those of the AIM were taken to an altitude of five thousand feet with a suspended weight of 300 pounds it appears that they are essentially equal within the accuracy of measurement.

The oscillation angles of the GQ Type 2000 Aeroconical parachute and the AIM parachute are appreciably less than that for the ACES-II modified C-9 canopy.

Table V. Subsystem: Parachute

SUBSYSTEM: PARACHUTE

	MIL-S-9479B	S4S	ACES-II	NACES
1.	PARAGRAPH 3.4.8 AIR FORCE APPROVED CANOPY	29.6 FT DIA. A.I.M. AIR FORCE QUALIFIED	28 FT C-9 MODIF. AIR FORCE QUALIFIED	6.2 & 6.5 METER AEROCONICAL U.S.N. QUALIFIED
2.	PARAGRAPH 3.4.8.1 PROVISIONS FOR MANUAL OVERRIDE PARACHUTE DEPLOYMENT	YES	YES	YES
3.	PARAGRAPH 3.4.8.2 SEAT/MAN SEPARATION BY PARACHUTE FORCES	YES	YES	YES

2.1.3 Comparison of Demonstrated Performance. Figures 5, 6, and 7 are graphical comparisons of the demonstrated performance of the three baseline ejection seats. The first figure illustrates the time required for the aerodynamic stabilization subsystems (drogue parachutes and fins) to become effective. This figure also presents the time to catapult separation and/or booster rocket ignition for reference since this is the approximate point in the ejection process where airspeed and altitude sensing begins and, in some cases, time delays are selected and started. The second figure presents the time required for the recovery parachute to reach "first full inflation" as a function of the airspeed at ejection. Although this event is subject to interpretation by the data analyst, it is considered here to be the most significant parameter available for comparison. Equally or more significant parameters such as the times to final full inflation, vertical descent or terminal velocity are seldom, if ever, observable in ground level track tests which are the source of most of the data. Tables VI through XV are included herein to provide details of the conditions in which the tests were performed. The paragraphs which follow in this section of the report are included as additional comments about some of the individual tests and the various test series. The Paragraphs following these tables are the annotated footnotes in these tables.

The data in Table VI is from a series of eight tests conducted with company funding at its Hurricane Mesa Track Test Facility near St. George, Utah. The ejection seats used in the tests were the generic S4S configuration. The on-seat post ejection sequencers were set to operate the drogue release and parachute container opener when the airspeed was at or below 300 KEAS and the pressure altitude was at or below 15,000 feet.

The on-seat sequencer sensed 300 KEAS and operated the drogue release and parachute container opener 0.757 seconds after catapult separation. This is indicative of the amount of time required for the 295 lb ejected weight to decelerate from 604 to 300 KEAS.

The on-seat sequencer sensed 300 KEAS and operated the drogue release and parachute container opener 0.377 seconds after catapult separation. This is indicative of the amount of time required for the 301 lb ejected weight to decelerate from 349 to 300 KEAS.

The on-seat sequencer sensed 300 KEAS and operated the drogue release and parachute container opener 0.358 seconds after catapult separation. It was concluded (Stencel Aero Corp, 1986) that these events were premature and that the actual airspeed was 348 KEAS at this time.

The on-seat sequencer sensed 300 KEAS and operated the drogue release and parachute container opener 0.965 seconds after catapult separation. It was concluded (Stencel Aero Corp, 1986) that these events should have occurred sooner and that the actual airspeed was 244 KEAS at this time.

This test was unique in the series in that drogue release and parachute container opener were not initiated by the sensed airspeed and altitude but were initiated by a time delay of 1.300 seconds after catapult separation. This is the computed time required for a 369 lb ejected weight to decelerate from 600 KEAS to 300 KEAS.

The data summarized in Table VII is from a series of ten tests which were conducted under contract to the USAF at the Holloman AFB Track Test Facility. The test seats were generic ACES II configuration and were conducted to qualify the baseline ejection seat.

The recovery sequencing system is assumed to have selected mode 2 as the time from catapult separation to recovery parachute mortar firing was 0.849 seconds which is within system tolerances for mode 2.

TIME TO DROGUE INFLATION AND FIN DEPLOYMENT DEMONSTRATED PERFORMANCE

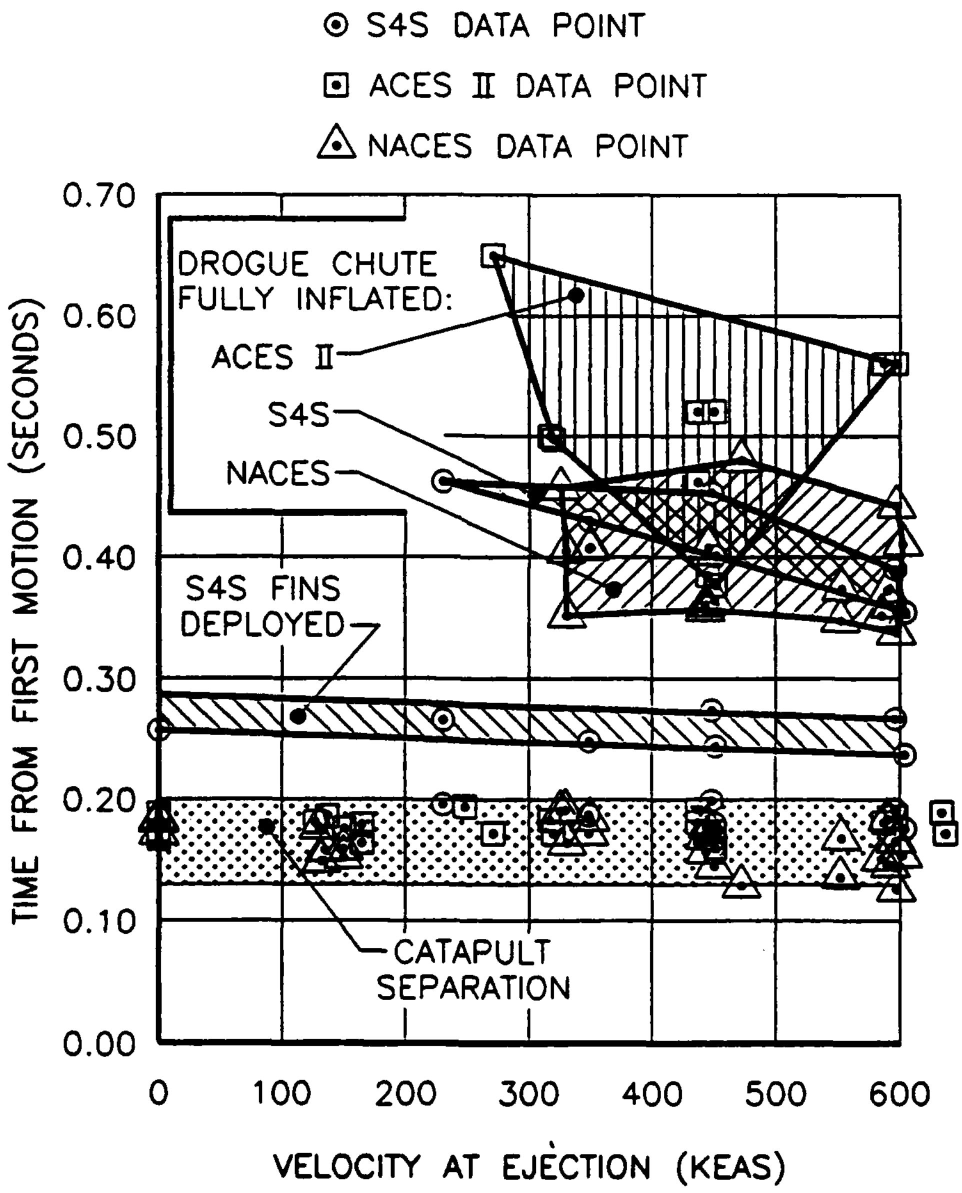


Figure 5
Time to Drogue Inflation and Fin Deployment Demonstrated Performance

TIME TO FIRST FULL INFLATION DEMONSTRATED PERFORMANCE

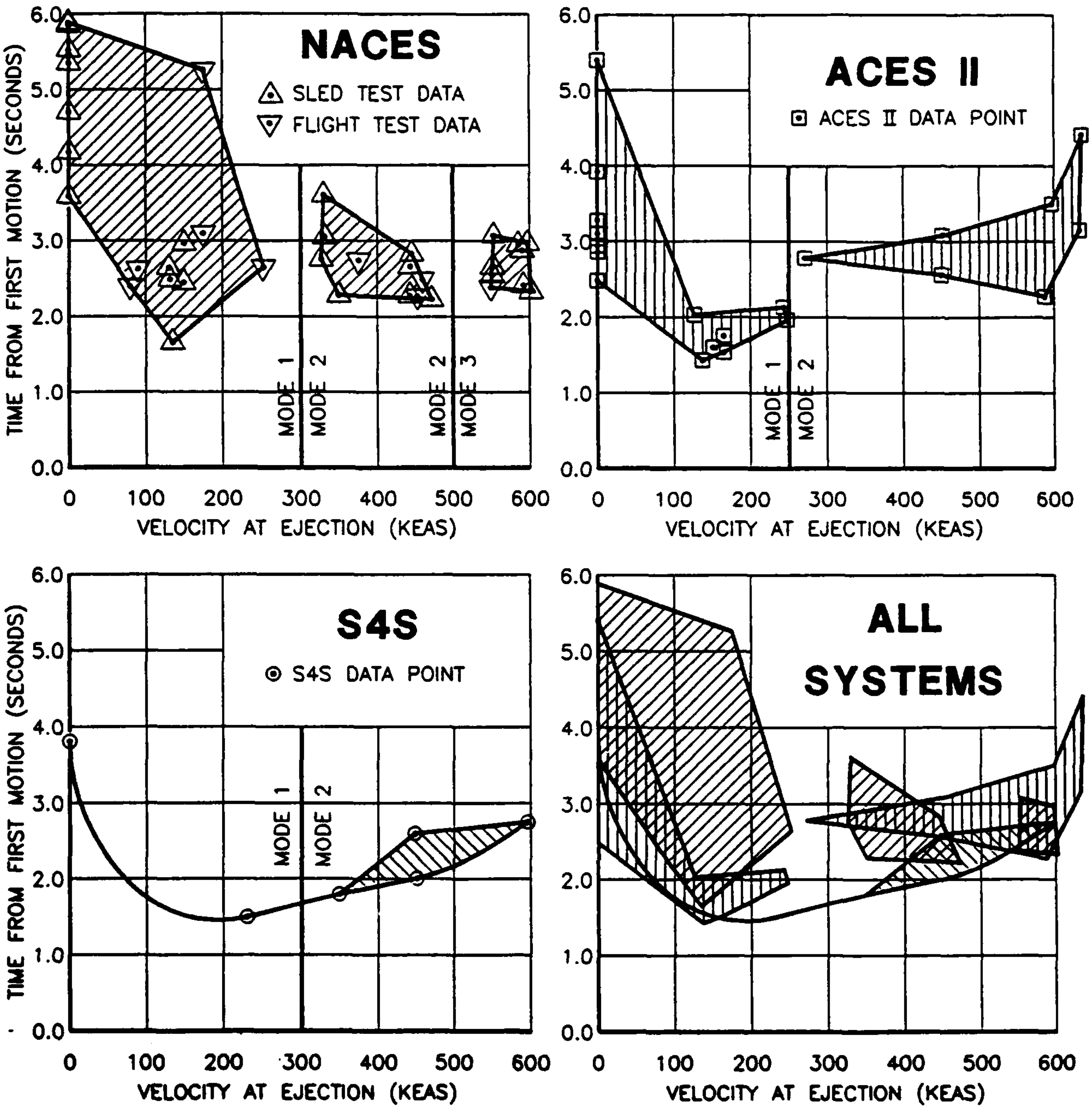


Figure 6
Time to First Full Inflation Demonstrated Performance

	S4S	ACES II	NACES
CATAPULT:		REF (l) & (g)	REF (d)
STROKE LENGTH (INCHES)	39	34	40
GUIDED LENGTH (INCHES)	32	33–38	21
NO. OF FIRING PINS/PRIMERS	4	2	2
SUSTAINER ROCKET(S):		REF (g)	REF (k)
BURN TIME (SEC)	0.25	0.30	0.25
X–Z PLANE IMPULSE (LB–SEC)	1130	1150	1220
THRUST ANGLE (DEG. TO CAT.)	40	54	25
DROGUE PARACHUTE:		REF (g)	REF (d)
TYPE	RIBLESS G. S.	HEMISFLO	20° CONICAL
CONSTRUCTION	SOLID	RIBBON	RIBBON
DIAMETER (INCHES)	39	60	57
MEANS OF DEPLOYMENT	MORTARED CONTAIN.	SLUG+EXT. CHUTE	MORTARED CONTAIN.
ADDITIONAL STABILIZATION SYSTEMS:		REF (g)	REF (d)
PITCH AXIS	DART	STAPAC	NONE
ROLL AXIS	DART	NONE	NONE
YAW AXIS	FINS	NONE	NONE
RECOVERY PARACHUTE:		REF (g)	REF (d)
TYPE	A.I.M.	FLAT CIRCULAR	AEROCONICAL
DIAMETER (FEET)	29.6	28.0	20.3
MEANS OF DEPLOYMENT	ROCKET+DROGUE	MORTAR+PIL. CHUTE	ROCKET
DIRECTION OF DEPLOYMENT	DOWNSTREAM	CROSS STREAM	CROSS STREAM
WEIGHT (W/O SURV. ITEMS–LBS):	REF (j)	REF (g)	REF (f)
EJECTED PORTION OF SEAT	134.7	137.8	193.3
NON–EJECTED PORTION (MIN)	5.0	16.0 (EST.)	16.0 (EST.)
MINIMUM INSTALLED WEIGHT	139.7	153.8	208.3
SRP TO A/C INTERFACE (INCHES)	3.50	6.75	7.50

Figure 7
Subsystem Comparisons

Table VI. System: S4S

TEST DATE	27Aug85	30Aug85	18Sep85	24Sep85	26Sep85	04Oct85	09 Oct85	17Oct85
COCKPIT	UTILITY	UTILITY	UTILITY	UTILITY	UTILITY	UTILITY	UTILITY	UTILITY
DUMMY PERCENTILE	95	5	95	95	5	5	95	95
EJECTED WEIGHT BS)	360	295	365	364	301	301	364	369
RECOVERED WEIGHT (LBS)	238	175	243	243	180	180	243	239
VELOCITY AT EJECTION (KEAS)	0	604	0	230	349	451	448	596
TEMPERATURE (°F)	84.0	88.0	86.0	70.0	74.0	70.0	60.0	67.0
PRESSURE (PSF)	1726	1732	1727	1591	1723	1740	1709	1718
DENSITY (SLUGS/FT^3)	.001851	.001843	.001844	.001751	.001882	.001915	.001917	.001901
DENSITY ALTITUDE (FEET)	8293	8417	8393	10,066	7750	7187	7152	7416
MACH NUMBER	0	1.010	0	0.401	0.585	0.753	0.754	1.001
CORRECT MODE	1	2	1	1	2	2	2	2
SELECTED MODE	1	2	1	1	2	2	2	P.S.2
TIME FROM 1ST MOTION (SEC)								
CATAPULT SEPARATION	NR	0.176	0.186	0.196	0.187	0.180	0.199	0.192
STABIL FINS DEPLOYED	NR	0.237	0.257	0.266	0.248	0.244	0.274	0.267
DROGUE INFLATION	NR	0.355	0.455	0.462	0.430	0.401	0.453	0.390
MAIN PC 1ST INFLATION	D.N.O.	N.R.	3.810	1.500	1.800	2.010	2.597	2.751
DATA REFERENCE	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
NOTE NUMBER		3.1.1			3.1.2	3.1.3	3.1.4	3.1.5

N.A. = Not Applicable   N.R. = Not Recorded   D.N.O. = Did Not Occur   P.S. = Pre-Selected

Table VII. System: ACES II

TEST DATE	13Feb73	13Mar73	20Mar73	27Mar73	10Apr73	19Apr73	24Apr73	03May73
COCKPIT	F-105	F-105	F-105	F-105	F-105	F-105	F-105	F-105
DUMMY PERCENTILE	HIGH C.G.	HIGH C.G.	95	5	95	LOW C.G.	95	5
EJECTED WEIGHT (LBS)	339	338	385	313	389	316	385	312
RECOVERED WEIGHT (LBS)	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.
VELOCITY AT EJECTION (KEAS)	0	0	248	587	597	0	450	271
TEMPERATURE (^{o}F)	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.
PRESSURE (PSF)	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.
DENSITY ($SLUGS/FT^3$)	-	-	-	-	-	-	-	-
DENSITY ALTITUDE (FEET)	-	-	-	-	-	-	-	-
MACH NUMBER	-	-	-	-	-	-	-	-
CORRECT MODE	1	1	1	2	2	1	2	2
SELECTED MODE	1	1	P.S.1	2	2	1	2	P.S.2
TIME FROM 1^{ST} MOTION (SEC)								
CATAPULT SEPARATION	0.170	0.174	0.194	0.185	0.186	0.167	0.174	0.182
STABIL FINS DEPLOYED	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
DROGUE INFLATION	N.A.	N.A.	N.A.	0.56	0.56	N.A.	0.52	0.65
MAIN PC 1ST INFLATION	5.40	3.10	1.96	2.27	3.50	2.86	2.56	2.78
DATA REFERENCE	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
NOTE NUMBER				3.2.1	3.2.1			

N.A. = Not Applicable   N.R. = Not Recorded   D.N.O. = Did Not Occur   P.S. = Pre-Selected

Table VII. (Continued) System: ACES II

TEST DATE	17May73	01Jun73						
COCKPIT	F-105	F-105						
DUMMY PERCENTILE	5	95						
EJECTED WEIGHT (LBS)	314	387						
RECOVERED WEIGHT (LBS)	N.R.	N.R.						
VELOCITY AT EJECTION (KEAS)	243	127						
TEMPERATURE (^{o}F)	N.R.	N.R.						
PRESSURE (PSF)	N.R.	N.R.						
DENSITY ($SLUGS/FT^3$)	-	-						
DENSITY ALTITUDE (FEET)	-	-						
MACH NUMBER	-	-						
CORRECT MODE	1	1						
SELECTED MODE	P.S.1	1						
TIME FROM 1^{ST} MOTION (SEC)								
CATAPULT SEPARATION	0.172	0.181						
STABIL FINS DEPLOYED	N.A.	N.A.						
DROGUE INFLATION	N.A.	N.A.						
MAIN PC 1ST INFLATION	2.13	2.03						
DATA REFERENCE	(a)	(a)						
NOTE NUMBER								

N.A. = Not Applicable N.R. = Not Recorded D.N.O. = Did Not Occur P.S. = Pre-Selected

Table VIII. System: ACES II

TEST DATE	03Feb76	10Feb76	17Feb76	24Feb76	02Mar76	09Mar76	16Mar76	23Mar76
COCKPIT	A-10	A-10	A-10	A-10	A-10	A-10	A-10	A-10
DUMMY PERCENTILE	5	95	5	95	5	95	5	95
EJECTED WEIGHT (LBS)	344	406	335	416	342	415	333	405
RECOVERED WEIGHT (LBS)	211	275	203	283	210	284	201	274
VELOCITY AT EJECTION (KEAS)	0	0	437	137	320	437	151	317
TEMPERATURE (^{o}F)	63.0	54.6	54.0	62.3	63.5	55.3	52.0	65.2
PRESSURE (PSF)	1823	1832	1835	1828	1819	1826	1847	1828
DENSITY (SLUGS/FT^3)	.002034	.002078	.002083	.002042	.002028	.002068	.002105	.002031
DENSITY ALTITUDE (FEET)	5228	4522	4442	5099	5326	4681	4093	5277
MACH NUMBER	0	0	0.710	0.223	.522	.712	.245	.516
NORMAL MODE	1	1	2	1	2	2	1	2
SELECTED MODE	1	1	2	1	2	2	1	2
TIME AFTER INITIATION (SEC)								
CATAPULT SEPARATION	0.183	0.188	0.181	0.186	0.172	0.192	0.176	0.183
STABIL FINS DEPLOYED	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
DROGUE INFLATION	N.A.	N.A.	0.520	N.A.	0.497	0.462	N.A.	0.500
MAIN PC 1ST INFLATION	2.940	3.280	2.100	1.430	2.080	2.421	1.597	2.112
DATA REFERENCE	(h)	(h)	(h)	(h)	(h)	(h)	(h)	(h)
NOTE NUMBER			3.3.1		3.3.1	3.3.1		3.3.1

N.A. = Not Applicable   N.R. = Not Recorded   D.N.O. = Did Not Occur   P.S. = Pre-Selected

Table IX. System: ACES II

TEST DATE	19Apr76	19Apr76	29Apr76	29Apr76	13May76	13May76	27May76	27May76
COCKPIT	TF-15 FWD	TF-15 AFT	TF-15 FWD	TF-15 AFT	TF-15 FWD	TF-15 AFT	TF-15 FWD	TF-15 AFT
DUMMY PERCENTILE	5	95	5	95	5	95	95	5
EJECTED WEIGHT (LBS)	234	415	335	415	344	407	407	345
RECOVERED WEIGHT (LBS)	200	283	202	282	211	274	274	212
VELOCITY AT EJECTION (KEAS)	0	0	637	634	165	165	445	451
TEMPERATURE (°F)	60.8	60.8	68.1	68.1	63.6	63.6	73.8	73.8
PRESSURE (PSF)	1826	1826	1823	1823	1768	1768	1822	1822
DENSITY (SLUGS/FT^3)	.002046	.002046	.002014	.002014	.001970	.001970	.001992	.001992
DENSITY ALTITUDE (FEET)	5034	5034	5547	5547	6271	6271	5918	5918
MACH NUMBER	0	0	1.038	1.033	.273	.273	.726	.735
CORRECT MODE	1	1	2	2	1	1	2	2
SELECTED MODE	1	1	2	2	1	1	2	2
TIME FROM 1ST MOTION (SEC)								
CATAPULT SEPARATION	0.167	0.172	0.172	0.189	0.179	0.164	0.174	0.160
STABIL FINS DEPLOYED	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
DROGUE INFLATION	N.A.	N.A.	N.R.	N.R.	N.A.	N.A.	0.385	0.377
MAIN PC 1ST INFLATION	3.924	2.481	4.418	3.151	1.536	1.750	D.N.O.	3.083
DATA REFERENCE	(h)	(h)	(h)	(h)	(h)	(h)	(h)	(h)
NOTE NUMBER			3.4.1	3.4.2			3.4.3	3.4.4

N.A. = Not Applicable N.R. = Not Recorded D.N.O. = Did Not Occur P.S. = Pre-Selected

Table X. System: NACES

TEST DATE	06May87	19Jun87	01Jul87	15Jul87	31Jul87	06Aug87	13Aug87	
COCKPIT	YF-4J	YF-4J	YF-4J	YF-4J	YF-4J	YF-4J	YF-4J	
DUMMY PERCENTILE	98	98	98	98	3	3	98	
EJECTED WEIGHT (LBS)	471	471	475	474	392	392	475	
RECOVERED WEIGHT (LBS)	257	257	257	259	175	175	259	
VELOCITY AT EJECTION (KEAS)	80	90	175	350	445	550	500	
TEMPERATURE (°F)	92	98	107.8	81	-37.6	91.4	55.9	
PRESSURE (PSF)	1958	1945	1622	1711	1233	1830	1531	
DENSITY (SLUGS/FT^3)	.002070	.002034	.001667	.001844	.001704	.001937	.001732	
DENSITY ALTITUDE (FEET)	4652	5229	11,636	8396	10,949	6836	10,430	
MACH NUMBER	0.126	0.142	0.302	0.589	0.882	0.895	0.889	
CORRECT MODE	1	1	1	2	4	3	4	
SELECTED MODE	1	1	1	4	4	4	5	
TIME FROM 1ST MOTION (SEC)								
CATAPULT SEPARATION	0.183	0.219	0.232	0.205	0.189	0.200	0.234	
STABIL FINS DEPLOYED	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	
DROGUE INFLATION	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	
MAIN PC 1ST INFLATION	2.396	2.627	3.100	4.771	5.483	4.672	5.395	
DATA REFERENCE	(f)	(f)	(f)	(f)	(f)	(f)	(f)	
NOTE NUMBER				3.5.1		3.5.1	3.5.1	

N.A. = Not Applicable   N.R. = Not Recorded   D.N.O. = Did Not Occur   P.S. = Pre-Selected

Table XI. System: NACES

TEST DATE	09Nov87	13Nov87	20Nov87	02Dec87	22Mar88	25Mar88	05Apr88	19Apr88
COCKPIT	YF-4J	YF-4J	YF-4J	YF-4J	YF-4J	YF-4J	YF-4J	YF-4J
DUMMY PERCENTILE	3	3	3	98	98	3	98	98
EJECTED WEIGHT (LBS)	392	390	390	476	469	384	N.R.	472
RECOVERED WEIGHT (LBS)	175	174	174	260	257	171	N.R.	259
VELOCITY AT EJECTION (KEAS)	175	252	375	460	453	283	555	355
TEMPERATURE (°F)	43.5	45.1	51.8	50.0	50.0	-78.2	55.9	34.0
PRESSURE (PSF)	1657	1532	1676	1662	1652	236	1716	1461
DENSITY (SLUGS/FT^3)	.001920	.001770	.001911	.001902	.001890	.000361	.001941	.001726
DENSITY ALTITUDE (FEET)	7108	9736	7269	7427	7623	50,132	6762	10,537
MACH NUMBER	0.299	0.448	0.638	0.785	0.776	1.282	0.932	0.646
CORRECT MODE	1	2	2	3	3	5	3	4
SELECTED MODE	1	2	2	3	3	5	4	4
TIME FROM 1ST MOTION (SEC)								
CATAPULT SEPARATION	0.185	0.176	0.190	N.R.	0.167	N.R.	0.216	0.201
STABIL FINS DEPLOYED	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
DROGUE INFLATION	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.
MAIN PC 1ST INFLATION	5.257	2.645	2.742	2.488	2.269	116.841	4.870	4.271
DATA REFERENCE	(f)	(f)	(f)	(f)	(f)	(f)	(f)	(f)
NOTE NUMBER							3.6.1	

N.A. = Not Applicable   N.R. = Not Recorded   D.N.O. = Did Not Occur   P.S. = Pre-Selected

Table XI. (Continued) System: NACES

TEST DATE	29Apr88	05May88	21Nov88	11Jan89				
COCKPIT	YF-4J	YF-4J	YF-4J	YF-4J				
DUMMY PERCENTILE	98	98	98	3				
EJECTED WEIGHT (LBS)	472	470	468	388				
RECOVERED WEIGHT (LBS)	259	259	257	175				
VELOCITY AT EJECTION (KEAS)	450	148	550	551				
TEMPERATURE (°F)	30.4	19.9	20.3	17.8				
PRESSURE (PSF)	1221	1398	1717	1511				
DENSITY (SLUGS/FT^3)	.001453	.001700	.002086	.001846				
DENSITY ALTITUDE (FEET)	15,886	11,015	4391	8396				
MACH NUMBER	0.896	0.275	0.924	0.987				
CORRECT MODE	4	4	3	4				
SELECTED MODE	4	4	3	4				
TIME FROM 1ST MOTION (SEC)								
CATAPULT SEPARATION	0.247	0.179	0.209	0.184				
STABIL FINS DEPLOYED	N.A.	N.A.	N.A.	N.A.				
DROGUE INFLATION	N.R.	N.R.	N.R.	N.R.				
MAIN PC 1ST INFLATION	4.349	5.272	2.385	4.255				
DATA REFERENCE	(f)	(f)	(f)	(f)				
NOTE NUMBER								

N.A. = Not Applicable N.R. = Not Recorded D.N.O. = Did Not Occur P.S. = Pre-Selected

Table XII. System: NACES

TEST DATE	02Nov89	02Nov89	16Nov89	16Nov89	29Nov89	29Nov89	06Dec89	06Dec89
COCKPIT	TF-18 FWD	TF-18 AFT	TF-18 FWD	TF-18 AFT	TF-18 FWD	TF-18 AFT	TF-18 FWD	TF-18 AFT
DUMMY PERCENTILE	3	98	3	98	98	3	98	3
EJECTED WEIGHT (LBS)	392	475	391	473	473	391	472	390
RECOVERED WEIGHT (LBS)								
VELOCITY AT EJECTION (KEAS)	0	0	150	150	330	331	443	443
TEMPERATURE (°F)	68	68	70	70	58	58	69	69
PRESSURE (PSF)	N.R.	N.R.	1965	1965	1969	1969	1953	1953
DENSITY (SLUGS/FT^3)	-	-	.002164	.002164	.002218	.002218	.002154	.002154
DENSITY ALTITUDE (FEET)	-	-	3180	3180	2343	2343	3321	3321
MACH NUMBER	0	0	0.236	0.236	0.518	0.519	0.698	0.698
CORRECT MODE	1	1	1	1	2	2	2	2
SELECTED MODE	1	1	1	1	2	2	2	2
TIME FROM 1ST MOTION (SEC)								
CATAPULT SEPARATION	0.185	0.183	0.152	0.159	0.191	0.164	0.157	0.169
STAB FINS DEPLOYED	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
DROGUE INFLATION	N.R.	N.R.	N.R.	N.R.	.405	.352	.357	.361
MAIN PC 1ST INFLATION	5.525	5.350	2.962	2.449	3.605	3.052	2.277	2.661
DATA REFERENCE	(e)	(e)	(e)	(e)	(e)	(e)	(e)	(e)
NOTE NUMBER								

N.A. = Not Applicable N.R. = Not Recorded D.N.O. = Did Not Occur P.S. = Pre-Selected

Table XII. (Continued) System: NACES

TEST DATE	11Jan90	11Jan90						
COCKPIT	TF-18 FWD	TF-18 AFT						
DUMMY PERCENTILE	3	98						
EJECTED WEIGHT (LBS)	391	472						
RECOVERED WEIGHT (LBS)								
VELOCITY AT EJECTION (KEAS)	585	590						
TEMPERATURE (^{o}F)	66	66						
PRESSURE (PSF)	1962	1962						
DENSITY (SLUGS/FT^{3})	.002178	.002177						
DENSITY ALTITUDE (FEET)	2977	2977						
MACH NUMBER	0.919	0.927						
CORRECT MODE	3	3						
SELECTED MODE	3	3						
TIME FROM 1ST MOTION (SEC)								
CATAPULT SEPARATION	0.151	0.184						
STABIL FINS DEPLOYED	N.A.	N.A.						
DROGUE INFLATION	.352	.373						
MAIN PC 1ST INFLATION	2.952	2.873						
DATA REFERENCE	(e)	(e)						
NOTE NUMBER								

N.A. = Not Applicable N.R. = Not Recorded D.N.O. = Did Not Occur P.S. = Pre-Selected

Table XIII. System: NACES

TEST DATE	31Jan90	07Feb90	21Feb90	28Feb90	07Mar90	06Sep90		
COCKPIT	F-18	F-18	F-18	F-18	F-18	F-18		
DUMMY PERCENTILE	98	3	98	3	98	98		
EJECTED WEIGHT (LBS)	470	390	472	393	469	470		
RECOVERED WEIGHT (LBS)	257	173	258	176	255	256		
VELOCITY AT EJECTION (KEAS)	0	135	326	472	597	592		
TEMPERATURE (°F)	53	52	60	69	67	96		
PRESSURE (PSF)	N.R.	1943	1968	1964	1955	1940		
DENSITY (SLUGS/FT^3)	-	.002215	.002209	.002167	.002165	.002036		
DENSITY ALTITUDE (FEET)	-	2398	2490	3133	3160	5195		
MACH NUMBER	0	0.213	0.511	0.741	0.940	0.935		
CORRECT MODE	1	1	2	2	3	3		
SELECTED MODE	1	1	2	2	3	3		
TIME FROM 1ST MOTION (SEC)								
CATAPULT SEPARATION	0.182	0.158	0.190	0.129	0.166	0.146		
STABIL FINS DEPLOYED	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.		
DROGUE INFLATION	N.A.	N.A.	.457	.480	.442	.360		
MAIN PC 1ST INFLATION	5.855	1.653	2.757	2.230	D.N.O.	2.410		
DATA REFERENCE	(e)	(e)	(e)	(e)	(e)	(e)		
NOTE NUMBER								

N.A. = Not Applicable   N.R. = Not Recorded   D.N.O. = Did Not Occur   P.S. = Pre-Selected

Table IVX. System: NACES

TEST DATE	30Aug89	30Aug89	26Jul89	26Jul89	16Jul90	16Jul90	15Aug89	15Aug89
COCKPIT	F-14 FWD	F-14 AFT	F-14 FWD	F-14 AFT	F-14 FWD	F-14 AFT	F-14 FWD	F-14 AFT
DUMMY PERCENTILE	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.
EJECTED WEIGHT (LBS)	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.
RECOVERED WEIGHT (LBS)	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.
VELOCITY AT EJECTION (KEAS)	0	0	130	132	349	350	445	450
TEMPERATURE (^{o}F)	N.R.	N.R.	106	106	98	98	102	102
PRESSURE (PSF)	N.R.	N.R.	1946	1946	1954	1954	1946	1946
DENSITY (SLUGS/FT^3)	-	-	.002006	.002006	.002043	.002043	.002021	.002021
DENSITY ALTITUDE (FEET)	-	-	5680	5680	5077	5077	5447	5447
MACH NUMBER	0	0	0.205	0.208	0.550	0.551	0.702	0.710
CORRECT MODE	1	1	1	1	2	2	2	2
SELECTED MODE	1	1	1	1	2	2	2	2
TIME FROM 1ST MOTION (SEC)								
CATAPULT SEPARATION	0.172	0.183	0.177	0.149	0.172	0.184	0.178	0.145
STABIL FINS DEPLOYED	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
DROGUE INFLATION	N.A.	N.A.	N.A.	N.A.	0.407	0.408	0.408	0.365
MAIN PC 1ST INFLATION	4.703	5.889	2.643	2.489	2.277	2.282	2.828	N.A.
DATA REFERENCE	(e)	(e)	(e)	(e)	(e)	(e)	(e)	(e)
NOTE NUMBER								

N.A. = Not Applicable N.R. = Not Recorded D.N.O. = Did Not Occur P.S. = Pre-Selected

Table IVX. (Continued) System: NACES

TEST DATE	13Sep89	13Sep89						
COCKPIT	F-14 FWD	F-14 AFT						
DUMMY PERCENTILE	N.R.	N.R.						
EJECTED WEIGHT (LBS)	N.R.	N.R.						
RECOVERED WEIGHT (LBS)	N.R.	N.R.						
VELOCITY AT EJECTION (KEAS)	597	602						
TEMPERATURE (°F)	N.R.	N.R.						
PRESSURE (PSF)	N.R.	N.R.						
DENSITY (SLUGS/FT^3)	-	-						
DENSITY ALTITUDE (FEET)	-	-						
MACH NUMBER	-	-						
CORRECT MODE	3	3						
SELECTED MODE	3	3						
TIME FROM 1ST MOTION (SEC)								
CATAPULT SEPARATION	0.126	0.154						
STABIL FINS DEPLOYED	N.A.	N.A.						
DROGUE INFLATION	0.338	0.411						
MAIN PC 1ST INFLATION	2.965	2.332						
DATA REFERENCE	(e)	(e)						
NOTE NUMBER								

N.A. = Not Applicable N.R. = Not Recorded D.N.O. = Did Not Occur P.S. = Pre-Selected

Table XV. System: NACES

TEST DATE	01Jun89	01Jun89	07Jun89	07Jun89	26Sep90	26Sep90		
COCKPIT	T-45 FWD	T-45 AFT	T-45 FWD	T-45 AFT	T-45 FWD	T-45 AFT		
DUMMY PERCENTILE	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.		
EJECTED WEIGHT (LBS)	N.R.	N.R.	N.R	N.R.	N.R.	N.R.		
RECOVERED WEIGHT (LBS)	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.		
VELOCITY AT EJECTION (KEAS)	0	0	552	552	553	552		
TEMPERATURE (°F)	N.R.	N.R.	92	92	N.R.	N.R.		
PRESSURE (PSF)	N.R.	N.R.	1940	1940	N.R.	N.R.		
DENSITY (SLUGS/FT^3)	-	-	.002051	.002051	-	-		
DENSITY ALTITUDE (FEET)	-	-	4957	4957	-	-		
MACH NUMBER	0	0	0.872	0.872	-	-		
CORRECT MODE	1	1	3	3	3	3		
SELECTED MODE	1	1	3	3	3	3		
TIME FROM 1ST MOTION (SEC)								
CATAPULT SEPARATION	N.R.	N.R.	N.R.	N.R.	0.168	0.136		
STABIL FINS DEPLOYED	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.		
DROGUE INFLATION	N.A.	N.A.	N.R.	N.R.	0.374	0.348		
MAIN PC 1ST INFLATION	3.589	4.176	2.660	D.N.O.	3.070	2.546		
DATA REFERENCE	(e)	(e)	(e)	(e)	(e)	(e)		
NOTE NUMBER								

N.A. = Not Applicable N.R. = Not Recorded D.N.O. = Did Not Occur P.S. = Pre-Selected

The recovery sequencing system is assumed to have selected mode 2 as the time from catapult separation to recovery parachute mortar firing was 0.850 seconds which is within system tolerances for mode 2.

Eight tests of the ACES II system as configured for the A-10 aircraft were conducted at Holloman AFB under USAF contract. The major difference in the configuration of these seats to those used in the qualification program and the TF-15 compatibility tests from a system performance viewpoint was in the unique recovery sequencing system. Due to the 450 KT maximum speed capability of the A-10 aircraft, the mode 2 time delay was shortened by approximately 0.250 seconds for the A-10 configuration.

The drogue inflation data is included in Figure 5 but the recovery parachute first full inflation time is not included in Figure 6 because the reduced mode 2 time delay is not used in systems for high performance aircraft.

Four tests were conducted using a TF-15 sled wherein test seats were ejected form both the front and rear cockpits. The eight seats were configured for the TF-15 aircraft. These tests were conducted under contract at Holloman AFB.

The recovery parachute mortar fired 0.997 seconds after catapult separation which indicates the recovery sequencing system probably sensed mode 3 for approximately 0.147 seconds prior to starting the mode 2 time delay.

The recovery parachute mortar fired 1.242 seconds after catapult separation which indicates the recovery sequencing system probably sensed mode 3 for approximately 0.392 seconds prior to starting the mode 2 time delay.

The recovery parachute mortar fired 1.006 seconds after catapult separation which indicates the recovery sequencing system probably sensed mode 3 for approximately 0.156 seconds prior to starting the mode 2 time delay.

The recovery parachute mortar fired 0.981 seconds after catapult separation which indicates the recovery sequencing system probably sensed mode 3 for approximately 0.131 seconds prior to starting the mode 2 time delay.

Seven tests of the NACES system were conducted with the seat being ejected from the aft cockpit of a YF-4J aircraft. This test series was conducted by the U. S. Navy as Phase I of the flight test program. The tests were conducted at NWC, China Lake, California.

Data from three of these tests were not included in Figure 6 because of the increased time delay before start of parachute deployment due to sequencer selection of the wrong mode.

Phase II of the NACES system in-flight tests were conducted by the U. S. Navy from a YF-4J aircraft rear cockpit. Twelve tests were conducted in this series and were conducted at NWC, China Lake, California.

Data from this test was not included in Figure 6 because of the increased time delay before start of parachute deployment due to sequencer selection of the wrong mode.

Five dual seat tests were conducted from a TF-18 sled at NWC, China Lake, California. All of the data presented in Table XII are included in Figures 5 and 6.

Six single seat tests were conducted from an F-18 sled at NWC, China Lake, California. All of the data presented in Table XIII are included in Figures 5 and 6.

Five dual seat tests were conducted from the F-14 sled at NWC, China Lake, California. All of the data presented in Table XIV are included in Figures 5 and 6.

Three dual seat tests were conducted from the T-45 sled at NWC, China Lake, California. All of the data presented in Table XV are included in Figures 5 and 6.

2.1.4 Head and Neck Load Comparisons. None of the third generation seats being compared provide any type of head restraint or protection other than the headrest structure. However, due to the differences in their drag/mass ratios, the loads applied to the head and neck are influenced by the ejection seat system. These differences and their effect on the magnitude and direction of the loads on the head will be analyzed in this section. This analysis is very limited in scope primarily due to the paucity of available data.

2.1.4.1 Conditions Analyzed. The only seat attitude that will be evaluated here is zero degrees pitch and zero degrees yaw. Zero degrees pitch is defined here as that attitude wherein the seat back tangent line is normal to the airstream and which positions the seat occupant "face to the wind". This

attitude has been selected since it lends itself to more straightforward analysis and ease of visualization. It is also an attitude that will produce maximum or near maximum shear loads on the occupant's neck. In this attitude, the neck tension loads would be very much the same for the three systems and will not be analyzed herein. Other than the three different seats, the only other parameters that will be considered here are the size and weight of the occupant and conditions before and after drogue parachute inflation.

2.1.4.2 Effective Drag Areas. LME report ALSEE-98321-89-02, "Analysis of Neck Shear Force and Tension Load in High Speed Ejections" (1990), reports on a head and neck load study program and cites various reference sources for the information used in that analysis. This report will be used as the single reference source in this analysis. The polynomial expressions for the effective drag area of the ACES II Ejection Seat (occupied by either a 95th percentile male or a 5th percentile female dummy), a 50th percentile head with helmet and oxygen mask and an ACES-type (hemisflo) drogue parachute in the wake of an ejection seat contained in the LME report are used as a baseline for this analysis. The bracketed equation numbers herein are those used as identifiers in the LME report.

2.1.4.2.1 Ejection Seat and Occupant. Over many years of testing various types and scales of ejection seat models in wind tunnels, it has been concluded and reported by various investigators that the aerodynamic properties of an occupied ejection seat are primarily dependent on the seat occupant and not the seat itself. This is especially true of the "axial force" coefficient in the zero pitch attitude being considered here. It is for this reason that it is considered valid to assume that the effective drag area of the S4S, ACES II and NACES are the same and that it (the effective drag area) will vary only with the size of the seat occupant. Therefore, the following polynomial will be used to calculate the value of (CdS)seat as a function of Mach Number (M) with the coefficients (values of S,S1...) from [5.8] and [5.9]:

$$(CdS)seat=(S)+(S1*M)+(S2*M^2)+(S3*M^3)+(S4*M^4)$$

COEFFICIENT	S	S1	S2	S3	S4
LARGE PERCENTILE	4.6136	7.5402	-13.2030	13.2810	-4.2969
SMALL PERCENTILE	6.1370	-3.2378	7.2867	-2.6304	0

2.1.4.2.2 Drogue Parachute. The type and size of drogue parachutes used on the three ejection seats are listed in Figure 7. Data on a hemisflo type of drogue parachute was utilized in the analysis reported on in the LME report. The data was acquired in wind tunnel tests with the drogue inflated in the wake of an ejection seat. Although the ACES II system is the only one of the three that uses a hemisflo type of drogue, the data is used herein as the most valid data to apply to all three systems. The drogue used in the aforementioned tests was scaled to be representative of that used in the current ACES II design. Therefore, the polynomial coefficients developed in the LME report are used in this analysis as directly applicable to the ACES II and are multiplied by a "size factor" when applied to the S4S or NACES. The "size factor" is simply the ratio of the diameter of the drogue of the system being analyzed to the diameter of the ACES II drogue squared. The equation for the effective drogue area as a function of Mach Number (with the "size factor" added) and the "size factors" are as follows:

$$(CdS)drogue=Kd*(30.78-68.0278*M+59.933*M^2-16.9136*M^3) \quad [EQ. 5.7]$$

$$Kd\ (S4S)=(39/60)^2=.4225$$
$$Kd\ (ACES\ II)=1.00$$
$$Kd\ (NACES)=(57/60)^2=.9025$$

2.1.4.2.3 Head, Helmet and Oxygen Mask. The LME report corrected its referenced data for full scale and developed a polynomial expression for the effective drag area of a 50th percentile male wearing a helmet and oxygen mask. "Size factors" were derived for small and extra large sizes and will be used here for the small and large percentiles, respectively. The polynomial expression and the "size factors" are as follows:

$$(CdS)head=Ks*(.50253-1.16434*M+1.9359*M^2-.71357*M^3) \quad [EQ. 5.5]$$

Ks(small percentiles)=0.9
Ks(large percentiles)=1.1

2.1.4.3 Weights. Two group weights are required to calculate the head loads; the weight of the entire ejected mass and the weight of the head and all equipment mounted to it. Maximum and minimum values for these two groups are defined in the following paragraphs.

2.1.4.3.1 Head, Helmet and Oxygen Mask. The maximum and minimum nude body weights for the seat occupant in this analysis is 221.7 and 128.4 lbs.,respectively. It is assumed that the bare head is 7.1% of the body weight,producing a maximum bare head weight of 15.7 lbs. and a minimum value of 9.1 lbs. The weight of the helmet and oxygen mask are assumed to have a weight of 4.7 lbs. The difference in weight for the small and extra large helmet is considered negligible.

Wh(max)=15.7+4.7=20.4 lbs.

Wh(min)=9.1+4.7=13.8 lbs.

2.1.4.3.2 Ejected Weight. The ejected weight group is the sum of the nude weight of the seat occupant, clothing, worn equipment, survival kit contents and the ejected portion of the ejection seat. Maximum and minimum values for the survival kit contents are assumed to be 40 and 24 lbs., respectively. A range of 128.4 to 221.7 lbs (1st through 99th percentile USN male aviation personnel) is used for the nude weight of the seat occupant. Reference (m) identified the weight of the clothing and worn equipment range to be 24.1 to 44.6 lbs. The range of weights which must be added to the ejection seat weight is, therefore:

	MINIMUM	MAXIMUM
Survival Gear Contents	24.0	40.0
Nude Occupant	128.4	221.7
Clothing and Worn Equipment	24.1	44.6
Subtotal	176.5	306.3

The weight of the ejected portion of the seats are listed in Figure 7. When added to the subtotals above, the range of ejected weight for each system is obtained:

	S4S		ACES II		NACES	
	MIN	MAX	MIN	MAX	MIN	MAX
Occupant and Equip.	176.5	306.3	176.5	306.3	176.5	306.3
Ejection Seat	134.7	134.7	137.8	137.8	193.3	193.3
Total Weight (We)	311.2	441.0	314.3	441.1	369.8	499.6

2.1.4.4 Head Load Calculations. Figure 8(a) is a free body diagram of the seat in the face to wind attitude used in this analysis. Equation [5.1] of the LME report was derived by summing forces parallel to the X-axis:

$$ax=q*(CdS)*g/We \quad [EQ 5.1]$$

where: CdS is the effective drag area of the entire system
and q is the dynamic pressure in lbs/ft2

Figure 8(b) is a free body diagram of the occupant's head. Equation [5.3] of the LME report was derived by summing forces parallel to the X-axis:

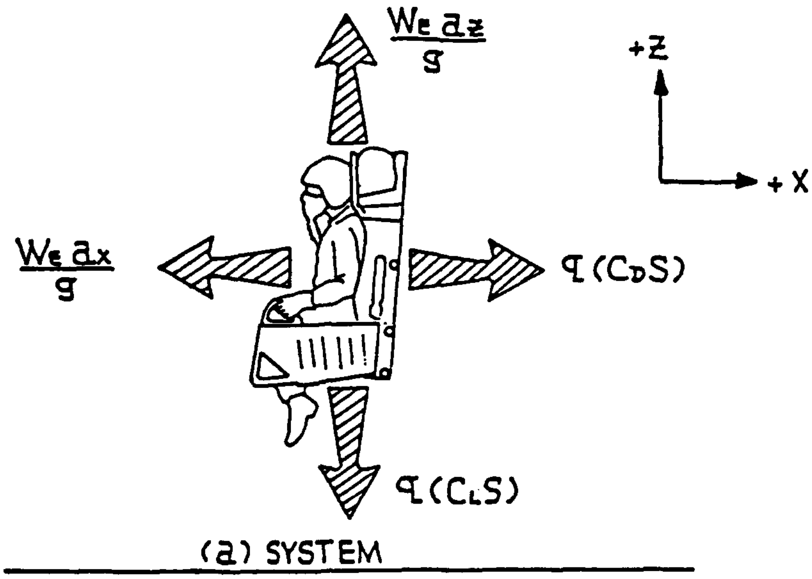
$$FHx/q=Ks*(CdS)head-(Wh/We)*[(CdS)seat+(CdS)drogue \quad [EQ 5.3]$$

where: FHx is the net force on the head in pounds

Values of FHx/q were computed for a range of Mach Numbers from 0.5 to 1.1 for twelve different combinations of seat (S4S, ACES II and NACES), occupant and equipment (maximum and minimum) and drogue (inflated and not inflated). The results of these computations are given in Table XVI and plotted in Figure 9.

2.1.4.5 Conclusions. While it is understood that Figure 9 cannot be used to quantify the head load per unit of pressure, it should be of sufficient validity to note the effects of the system differences. One obvious factor is the effect of the drogue parachutes on each of the three systems. The figure shows that before the drogue parachute becomes effective the net force on the head is aftward, pushing the head back against the headrest on all three systems. It is of interest that the magnitude of the forces encountered at the highest Mach Number considered here (Mach 1.1) range from .203*q for the S4S and ACES II to.336*q for the NACES. Taking these values as an example, at an airspeed of 602 KEAS at an altitude of 10,000 feet, the Mach Number would be 1.1 and the dynamic pressure (q) would be 1232 psf. Therefore, the occupant's head should be forced back against the headrest with a load of 250 to 414 pounds. Examination of the equations and system parameters presented previously shows that the NACES generally causes higher aft head loads prior to drogue inflation because its greater weight reduces the magnitude of the seat deceleration and the inertia force of the head thereby allowing the dynamic pressure on the head to be predominant.

The differences in the three systems become much more pronounced once the drogue parachutes become effective. For example, at Mach 0.7 at sea level the airspeed is 463 knots and the dynamic pressure is 725 psf. Under these conditions the small percentiles would experience 46 pounds (.064*725)in the S4S, 86 pounds (.118*725) in the NACES and 109 pounds (.118*725) in the ACES II.



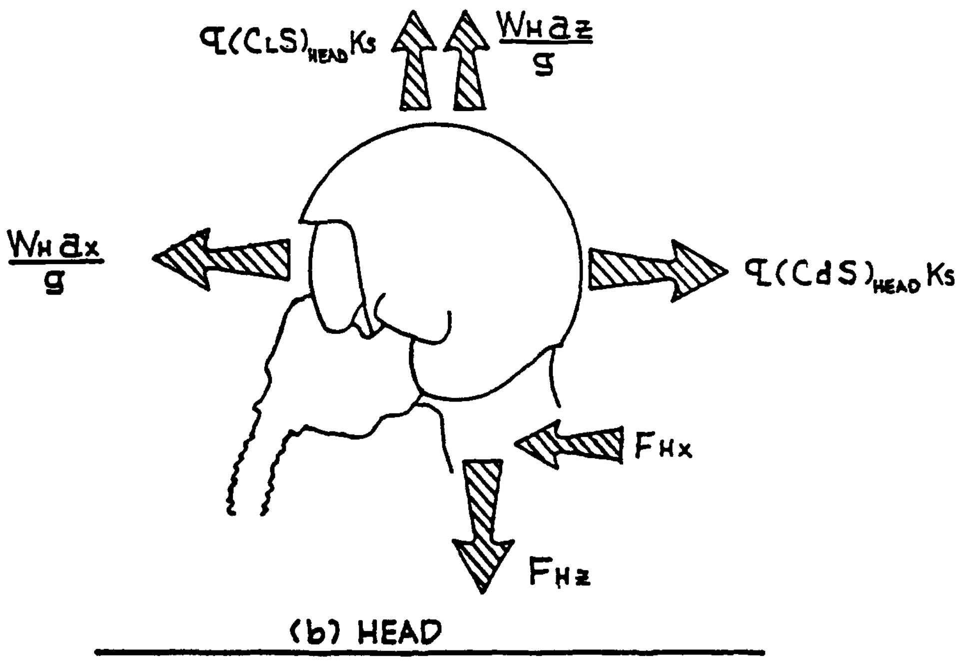


Figure 8
Free Body Diagrams

Table XVI. Head Load Comparisons

S4S
99th %ile MALE
DROGUE INFLATED

MACH NO.	FHX/Q
0.5	-0.141
0.6	-0.082
0.7	-0.022
0.8	0.036
0.9	0.090
1.0	0.137
1.1	0.175

ACES II
99th %ile MALE
DROGUE INFLATED

MACH NO.	FHX/Q
0.5	-0.393
0.6	-0.288
0.7	-0.198
0.8	-0.121
0.9	-0.060
1.0	-0.013
1.1	0.020

NACES
99th %ile MALE
DROGUE INFLATED .

MACH NO.	FHX/Q
0.5	-0.273
0.6	-0.183
0.7	-0.101
0.8	-0.029
0.9	0.031
1.0	0.080
1.1	0.117

S4S
1st %ile MALE
DROGUE INFLATED

MACH NO.	FHX/Q
0.5	-0.163
0.6	-0.113
0.7	-0.064
0.8	-0.018
0.9	0.025
1.0	0.061
1.1	0.092

ACES II
1st %ile MALE
DROGUE INFLATED

MACH NO.	FHX/Q
0.5	-0.403
0.6	-0.309
0.7	-0.230
0.8	-0.167
0.9	-0.117
1.0	-0.081
1.1	-0.055

NACES
1st %ile MALE
DROGUE INFLATED

MACH NO.	FHX/Q
0.5	-0.265
0.6	-0.187
0.7	-0.118
0.8	-0.060
0.9	-0.011
1.0	0.028
1.1	0.058

S4S
99th %ile MALE
DROGUE NOT INFLATED

MACH NO.	FHX/Q
0.5	0.047
0.6	0.072
0.7	0.109
0.8	0.154
0.9	0.203
1.0	0.250
1.1	0.291

ACES II
99th %ile MALE
DROGUE NOT INFLATED

MACH NO.	FHX/Q
0.5	0.049
0.6	0.074
0.7	0.111
0.8	0.157
0.9	0.205
1.0	0.252
1.1	0.294

NACES
99th %ile MALE
DROGUE NOT INFLATED

MACH NO.	FHX/Q
0.5	0.082
0.6	0.108
0.7	0.147
0.8	0.194
0.9	0.244
1.0	0.293
1.1	0.336

S4S
1st %ile MALE
DROGUE NOT INFLATED

MACH NO.	FHX/Q
0.5	0.017
0.6	0.035
0.7	0.062
0.8	0.096
0.9	0.133
1.0	0.169
1.1	0.203

ACES II
1st %ile MALE
DROGUE NOT INFLATED

MACH NO.	FHX/Q
0.5	0.020
0.6	0.038
0.7	0.065
0.8	0.099
0.9	0.136
1.0	0.173
1.1	0.207

NACES
1st %ile MALE
DROGUE NOT INFLATED

MACH NO.	FHX/Q
0.5	0.059
0.6	0.079
0.7	0.108
0.8	0.144
0.9	0.183
1.0	0.223
1.1	0.259

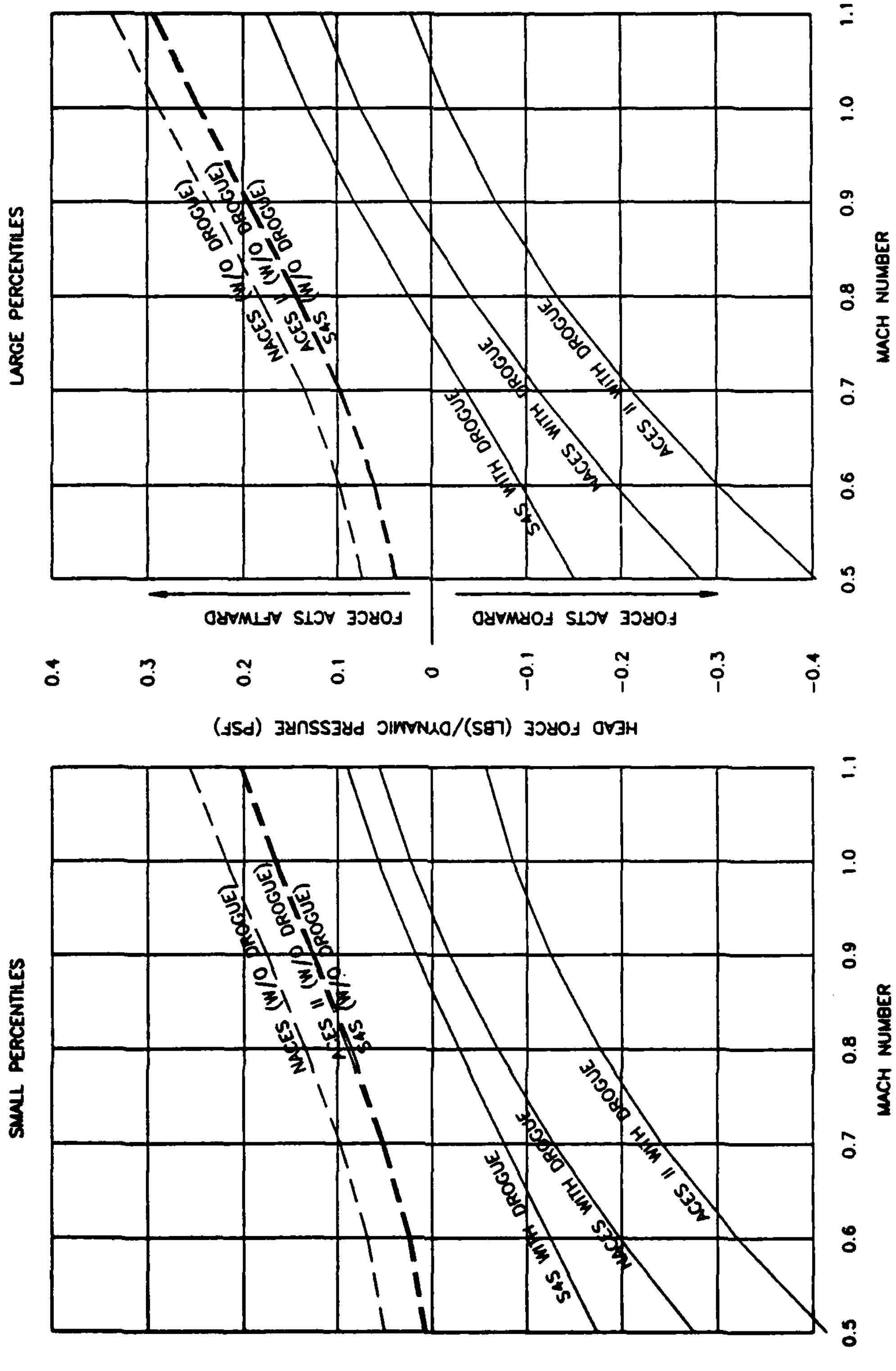


Figure 9
Head Force Normal to Spine Comparison

2.2 Task 2 - Performance Requirements of Future DoD Aircraft by Mission Type

2.2.1 Introduction. This task summarizes the operational characteristics of several future DoD aircraft. The aircraft assessments were based on previous designs developed by Rockwell International - North American Aircraft. Although most DoD aircraft are developed in a classified environment, all of the data presented within this report is unclassified. However, the configurations themselves are proprietary information to Rockwell International.

2.2.2 Objective. The objective of this task was to assess the operational requirements of future DoD aircraft. Because of the wide spectrum of operating environments between different classes of aircraft, a data base was established for each type of future DoD aircraft. The purpose of assembling this data base of operational parameters for various aircraft types was to define the future ejection / escape environment. By performing this type of an assessment for future DoD aircraft, the crew escape requirements for a given aircraft type will match the appropriate operational envelope instead of lagging behind by utilizing outdated requirements.

Each aircraft type has its own set of operational envelope and parameters. Some of these parameters are critical for successful ejection / escape systems. These critical ejection / escape parameters can include maximum dynamic pressure, load factors, Mach numbers, altitudes, stability margins and maximum attitude angles and rates. Some aircraft types also have unique operational requirements such as terrain following and carrier suitability. All of these factors must be collected or projected for future aircraft in order to establish proper crew escape requirements.

2.2.3 Approach.

2.2.3.1 Aircraft Systems Investigated. A wide spectrum of aircraft types were investigated so that a large and varied data base could be generated, Table XVII. The configurations, mission profiles and operational envelopes for these aircraft vary greatly from the subsonic trainer to the hypersonic interceptor. Listed in the table by mission type is the current system or systems as well as the projected replacement. Although some of these mission types already have identified replacements, the configurations used in the analysis are limited to Rockwell International designs that are unclassified. Most of the configurations are in the conceptual design phase where only a limited amount of information is known about the aircraft. However, it is during this conceptual design phase where approximately 80% of the aircraft operational characteristics are established. Therefore, it is critical to establish crew escape requirements for future aircraft during this design phase.

Table XVII. Mission Types Investigated In This Study

Mission Type	Existing System(s)	Rockwell International Study
Air Superiority	F-15	Initial ATF Study
Fighter	F-16	Multi-Role Fighter Study
Close Air Support	A-10	Close Air Support Study
Attack	A-6 / A-7	Initial AX Study
Primary Trainer	T-37	JPATS Study
Strategic Bomber	B-1B	BX Study
Special Operations	MC-130	SOF Study
Hypersonic Interceptor	None	Hypersonic DLI Study
Hypersonic Reconnaissance	None	SSTO Study

2.2.3.2 Aircraft Operational Envelopes and Requirements. For each of these aircraft systems, the operational limits were investigated. One of the most important parameters for ejection / escape parameters is the maximum dynamic pressure. The trend for future DoD aircraft is for larger flight envelopes by increasing the maximum dynamic pressure. However, by increasing the maximum dynamic pressure of the aircraft, serious attention must be given to wind blast protection and stability and control for the ejection / escape system.

Due to the great advances in materials and propulsion systems, flight envelopes of future aircraft are also expected to expand both in terms of speed and altitude. With the new propulsion developments such as scramjets, the speeds of future aircraft are capable of going beyond Mach 6 almost to the point of orbital speeds. Even turbo machinery propulsion systems are being projected up to Mach 5 with the new advances in materials. These turbo machinery propulsion systems are much more attractive to aircraft designers due to their significant fuel efficiency compared to ramjets and rockets. One substantial problem for crew escape during these high velocities is the very high temperatures that are incurred due to aerodynamic heating.

Altitude plays an important role both as future aircraft start to fly higher and lower than current systems. For many mission types, the upper altitude limit is increasing. This is especially true for hypersonic aircraft where the majority of the mission is at very high altitudes approaching over 100,000 ft. For crew escape at this altitude, the ejection / escape system is exposed to a long fall through a hostile environment.

Most of the future military aircraft systems require operations at low altitudes. Some common types of low altitude operations include terrain following / terrain avoidance (TF/TA) and maneuvers during ground attack. As radars become more advanced, the signature levels required to defeat the threats become more severe. Although low observable technologies are being developed to defeat these threats, detection levels can be reduced by flying at very low altitudes using terrain masking. The B-2 bomber is proposed to utilize terrain following in high threat scenarios. For ground attack aircraft, the vehicle is subjected to low altitude operations where dive angles and speeds are a concern. Takeoff and landing for all aircraft pose challenges for successful crew escape due to the proximity to the ground. The major problem for crew escape during low altitude operations is the potential for adverse attitudes of the aircraft in ground proximity. With the increased speed at low altitude, the ejection system must react almost instantaneously to allow for safe ejection / escape before the aircraft impacts the ground.

Another critical parameter that is sacrificed due to signature reduction is the forebody flow field. Some future DoD aircraft are proposed to have radically different forebody shapes in order to defeat the predicted threats. This is seen in the YF-23 and the cancelled A-12 where a conventional forebody is eliminated or altered in order to bring down the signature levels. It is not known whether the flow field is degraded for crew escape for these systems. However, it is assumed that there is a flow field penalty due to the unusual forebody shaping.

Another important parameter for escape systems is the maximum allowable load factor for the aircraft. Ejections at high aircraft loadings subject the crew members to severe conditions. Although there is a practical limit for maximum loadings on personnel due to g-induced loss of consciousness, technologies are being developed to delay this occurrence. Currently, to avoid most of the projected threats, loadings below 10 are assumed adequate for survival.

One of the more recent trends in aircraft design is to relax the static stability of the aircraft. This is accomplished by incorporating artificial stability into the aircraft where a computer directs the control surfaces or thrust deflections such that the aircraft is stable. This is opposed to the more conventional method of inherent aerodynamic stability. The advantages to relaxing the stability margin is that the aircraft can become more maneuverable and pays less of a trim drag penalty. However, in an emergency condition where the stability augmentation system fails, the aircraft could encounter severe adverse attitudes and load factors. From past experience, the attitude of the ejection / escape system must be controlled during ejection to achieve overall success. Therefore, any degradation of the aircraft stability at ejection presents a serious additional risk that the ejection / escape system must face.

As stated before, the attitude of the aircraft is extremely important in determining the escape requirements. For the various aircraft types, the aircraft attitude limits and maximum rates were requested in order to help define the crew escape requirements. The difficulty arose in that these limits and rates are very sensitive to the configuration and not necessarily representative of the aircraft type.

Pitch limits have been recently expanded beyond conventional stall limits for many new combat aircraft. Canards and thrust vectoring have allowed new aircraft like the X-31 to pursue operations beyond the stall limit. However, canards and thrust vectoring are not mandatory to operate beyond the stall limit. This has been seen by the Pougachev Cobra maneuver performed by the Soviets in a SU-27 in recent air shows. For hypersonic aircraft, pitch limits are important at high speeds. This is because the propulsion system is closely aligned with the external aerodynamics. This is seen in the proposed X-30 where the entire forebody is used as a compression surface for the engine inlet and the aftbody is used as an expansion nozzle. Typically, at very high Mach numbers, the aircraft is limited to small angles of attack. Roll limits are usually not defined for combat aircraft since most can do 360 degree rolls. However, the roll limits may exist for the Special Operations Aircraft and the strategic bomber. These roll limits are typically very configuration dependent and are not fully defined in the conceptual design level. Like the roll limits, yaw limits are rarely defined at the conceptual design level. Yaw limits are a strong function of the configuration as well as the speed and the pitch attitude. For these reasons, the roll and yaw limits were not tabulated for the various aircraft type.

Pitch, roll and yaw rates are a strong function of the control power of an aircraft. Two dimensional thrust vectoring and canards increase the pitch rate capability of an aircraft as demonstrated by the F-15 STMD and the new F-22 aircraft. Three dimensional thrust vectoring can increase the pitch and yaw rates as demonstrated by the thrust vectoring paddles on the X-31. Because the pitch and yaw rates are so configuration dependent, these values were not tabulated for the various aircraft types. Roll rates were tabulated for the various aircraft types. Minimum required roll rates are specified in MIL-F-8785, Flying Qualities of Piloted Aircraft, for various aircraft types during different flight phases. The most stringent roll rates are tabulated for each class of aircraft to be used as a guideline for the crew escape designer. Again it should be noted that these are the minimum requirements and that the actual roll rate limits may exceed the values tabulated (eg, F-22 maximum roll rate is reported to be 200+ degrees/second).

Because the crew escape requirements vary tremendously within a mission for varying flight phases, an escape system that meets all of the possible requirements will be too costly, weigh too much and may not even be technically achievable. To get a better appreciation of the amount of time that an aircraft spends within each portion of the flight envelope, typical mission breakdowns were evaluated for each aircraft class. From these mission breakdowns, the percentage of time that is spent in each portion of the flight envelope was plotted. Therefore, the crew escape requirements can be derived such that a future crew escape system will not be over designed due to an assumed requirement that hardly ever occurs.

Table XVIII summarizes the various operational requirements that were used in this study. The results for each of these requirements are shown in the following section.

2.2.4 Results. The results for the each of the aircraft types are shown in separate sections followed by a comparison of each of the classes. For each class of aircraft, a configuration drawing is shown for reference. The mission profile is assumed typical for this type of aircraft with some classes of aircraft having more than one profile. Some of the information is not applicable to all classes of aircraft and is noted in the appropriate sections. In addition, some of the information is not available and also noted in the appropriate sections.

2.2.4.1 Air Superiority

2.2.4.1.1 Configuration Dependent Parameters. An example of a typical air superiority aircraft is shown in Figure 10. This configuration uses a highly swept wing and twin engines for quick accelerations and cruises at high Mach numbers. At the objective area, the aircraft must have good maneuverability and have a large amount of excess energy capability to defeat the airborne threat.

To enhance the maneuverability and to reduce the trim drag penalty, the aircraft is to use relaxed static stability longitudinally. Goal stability levels of this configuration is for 5% unstable. In addition, the aircraft is to use two dimensional thrust vectoring and might have some limited post stall capability. The aircraft is capable of 360 degree rolls with a minimum roll rate defined in MIL-F-8785 to be 128 deg/s during aerial combat phases. The forebody is similar to the F-15 and is not expected to have an adverse flow field. The new F-22 also has a similar forebody shape as opposed to the YF-23 that has some forebody shaping to lower signature levels.

Table XVIII. Aircraft Operational Requirements Used For This Study

Configuration Dependent Parameters
Stability Margins
Attitude Limits and Rates
Forebody Flow Field Effects
Aircraft Operational Limits
Maximum Speed
Maximum Dynamic Pressure
Maximum Altitude
Maximum & Minimum Load Factors
Mission Characteristics
Mission Profile
% Flight Time in the Flight Envelope
Operational Requirements
Terrain Following / Terrain Avoidance
Speed
Altitude
Ground Attack
Dive Speed
Dive Angle
Takeoff and Landing Speeds
Liftoff or Touchdown
Obstacle

2.2.4.1.2 Aircraft Operational Limits. The speed-altitude envelope of the configuration is shown in Figure 11. The maximum dynamic pressure is 1,500 psf and defines the maximum allowable speed at sea level to be slightly over sonic conditions. The maximum speed limit at altitude is Mach 1.6 with the maximum altitude set at 60,000 ft. The loading limits are shown in Figure 12. The maximum load factor is 9 for subsonic speeds and decreases to 8 during supersonic operations. The minimum load factor is set to -4 for subsonic speeds and -5 for supersonic speeds. Both the speed-altitude limits and the load limits are set from the mission requirements. Note also that the lift limits are removed from both the speed-altitude envelope and the load factor limits. The main purpose of this is that this limit is dependent on aircraft weight and also by the fact that many future aircraft are exploring beyond conventional lift limits.

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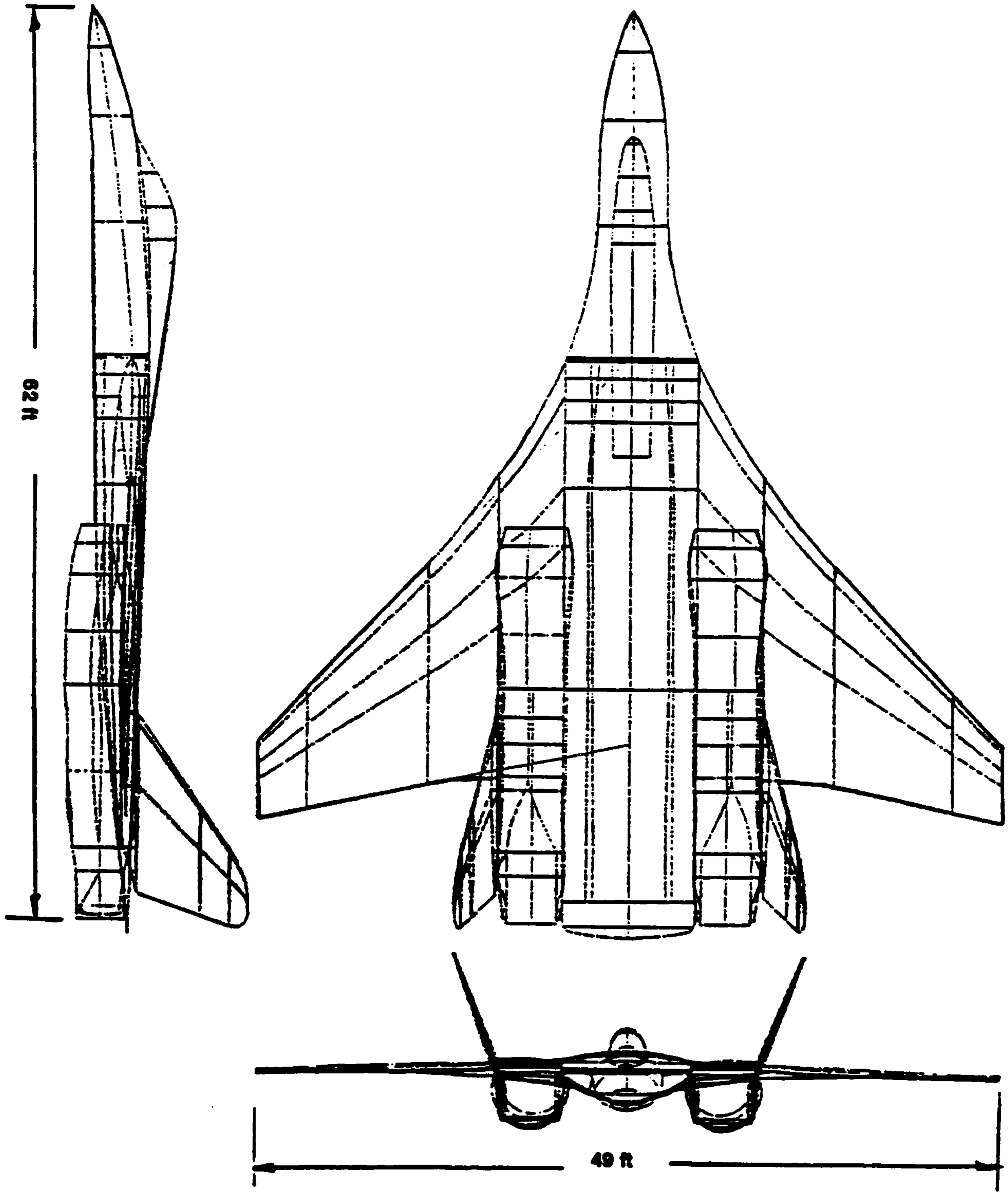


Figure 10
Typical Air Superiority Configuration

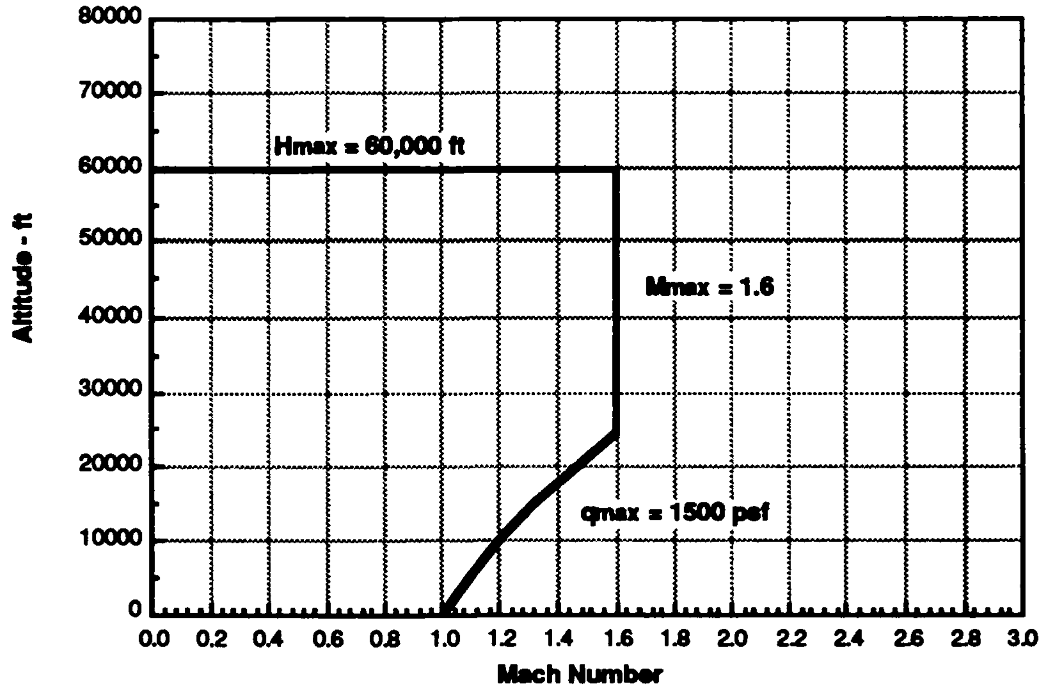


Figure 11
Speed - Altitude Limit Diagram

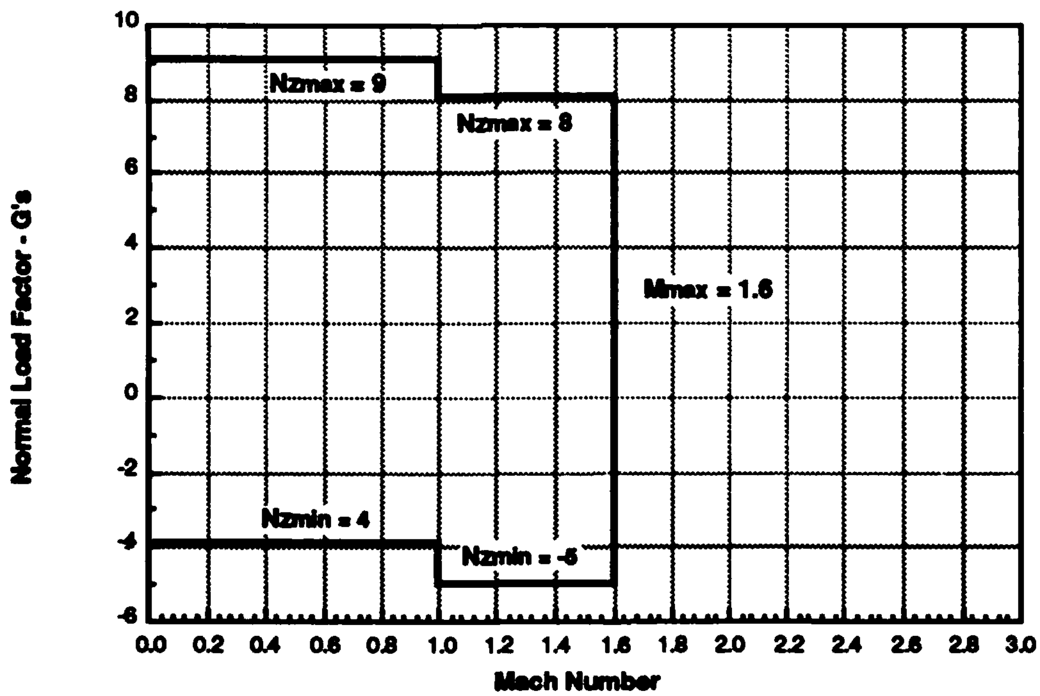


Figure 12
Limit Load Diagram

2.2.4.1.3 Mission Profile Characteristics. A typical mission profile is shown in Figure 13. After takeoff, the aircraft climbs up to the cruise altitude and Mach number for best range. For most aircraft, this speed is typically subsonic as it is for this specific aircraft. At about 100 nautical miles (nm) from the target, the aircraft accelerates to supersonic speeds and locates the target. If a first shot is not taken by the aircraft, an aerial combat might occur. The combat may occur at supersonic speeds, but will usually go to subsonic speeds during some portion of the combat. Assuming a 2 minute allowance for combat, the aircraft then retreats from the area supersonically. After a safe distance away, the vehicle slows down to best cruise speed and altitude. Upon return to the base, a 20 minute loiter is included for reserves.

The amount of flight time spent in each portion of the speed-altitude envelope is shown in Figure 14. As can be seen, 40 to 50% of the mission is during the cruise legs at subsonic speeds. The cruise altitudes vary from 40,000 ft to 50,000 ft depending on mission weight and the cruise speed is near Mach 0.9. The climb portion up to the cruise condition takes 5 to 10% of the mission time and is always subsonic. The acceleration from subsonic cruise to supersonic penetration is less than 5% of the mission time. The path may decrease in altitude at the start of the acceleration to optimize the climb path. However, this is very configuration dependent. The penetration leg is supersonic at Mach 1.5 and 50,000 ft. For ingress and egress, the total time at this flight condition represents 10 to 20% of the mission. The loiter represents the remaining 10 to 20% of the mission time. Note that the majority of the speed-altitude envelope is not utilized for this mission. This is typical for most aircraft and is represented in the other aircraft classes.

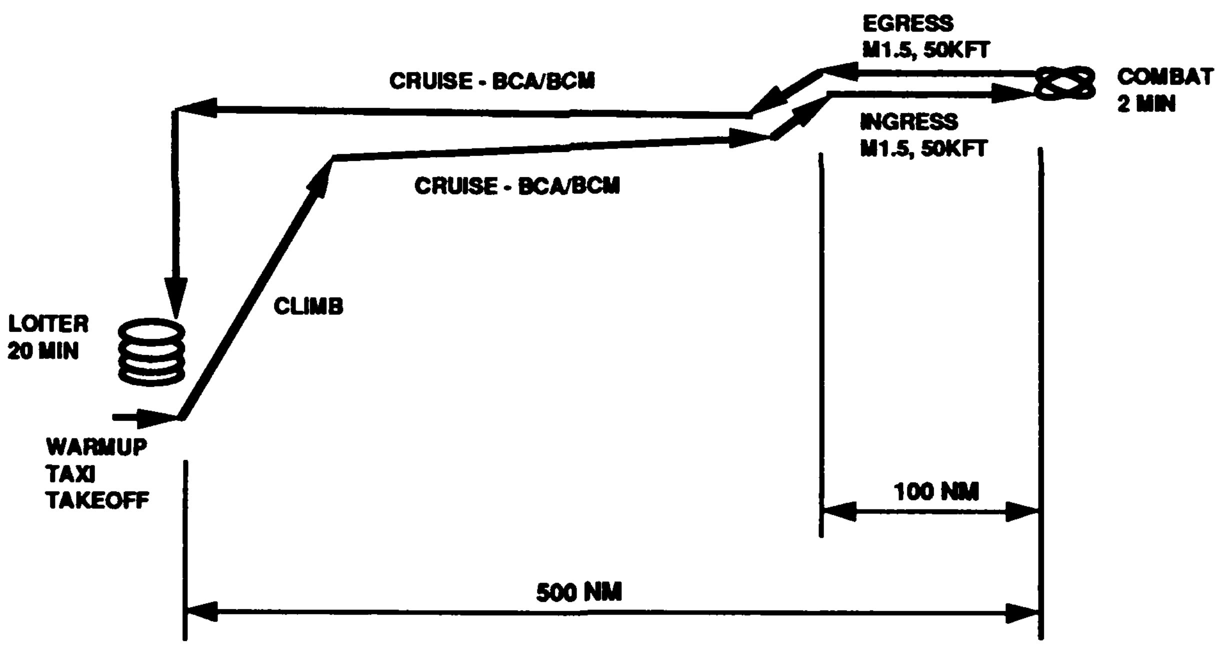


Figure 13
Air Superiority Mission Profile

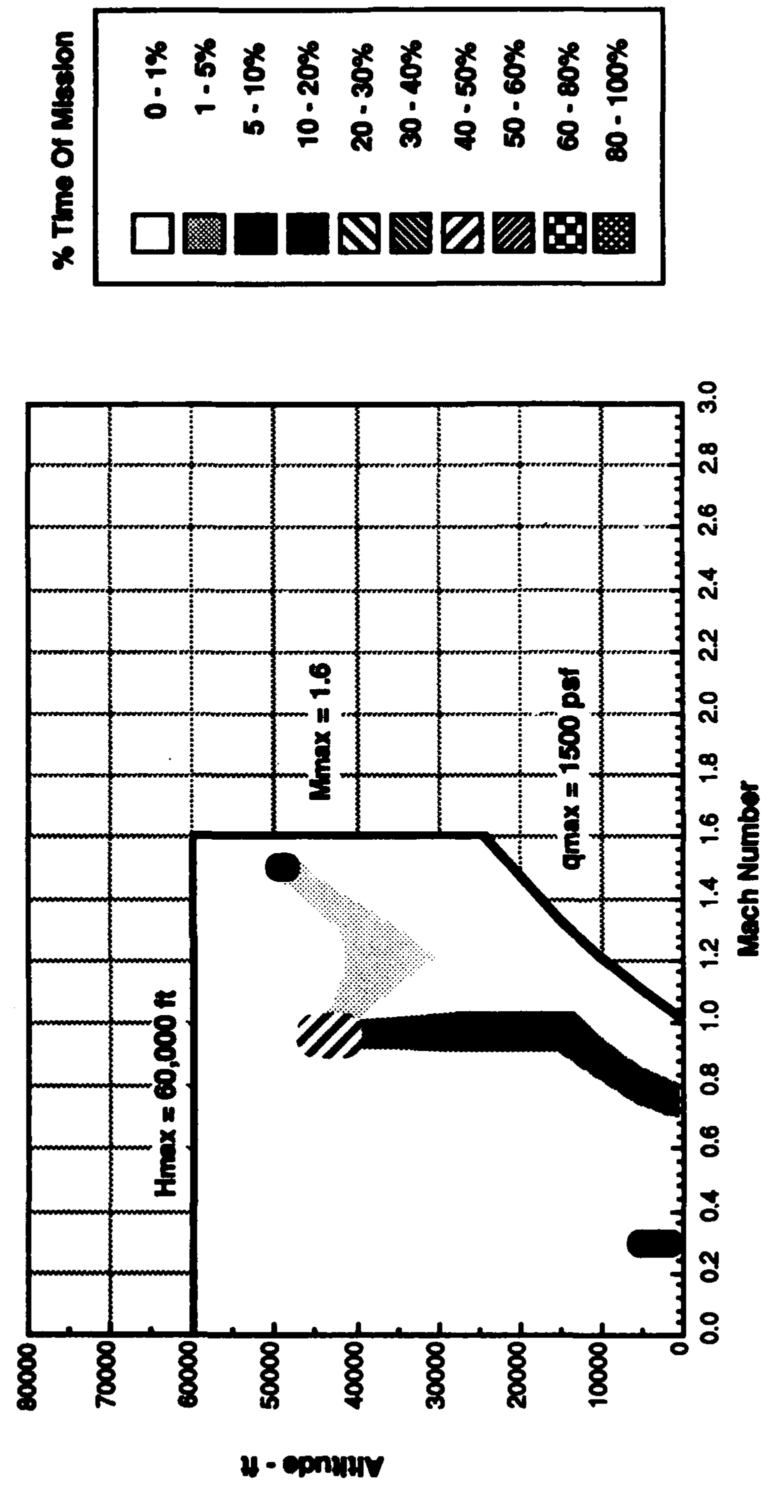


Figure 14
Mission Flight Time Breakdown

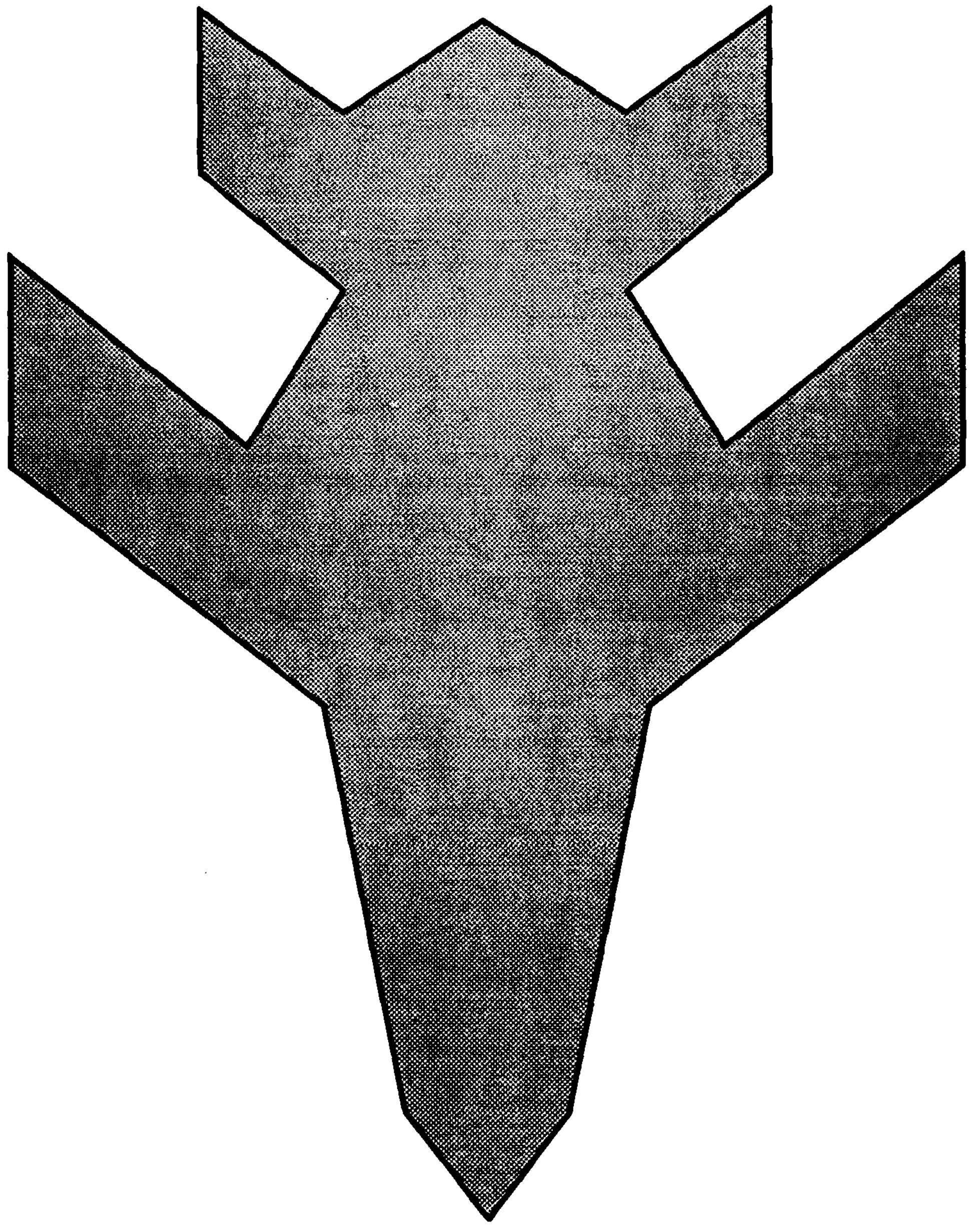
2.2.4.1.4 Operational Characteristics. This configuration does not have any significant low altitude operations apart from takeoff and landing. During takeoff at maximum weight, the configuration lifts off at 132 knots and passes over the obstacle at 144 knots. For an assumed landing weight with 80% fuel out, the aircraft passes over the obstacle at 114 knots and touches down at 104 knots.

2.2.4.2 Fighter

2.2.4.2.1 Configuration Dependent Parameters. For a multi-role fighter that replaces the F-16, the configuration must be flexible enough to perform a variety of mission roles. These missions include combat air patrol, air interdiction, and battle field interdiction. Therefore, the flight envelope of this configuration is expected larger than most of the other aircraft. The configuration used in this study is shown in Figure 15. The configuration balances aerodynamic performance and stealth with relatively moderate sweeps. Like the F-16, it is a single engine aircraft.

Like most fighter aircraft, the maneuver requirements are a big driver for this configuration. To enhance the maneuverability of this configuration, the static stability was relaxed to approximately 5% unstable. The configuration also uses two dimensional thrust vectoring to enhance the maneuverability. This might allow some operations beyond conventional stall limits but is not known to what extent. The aircraft is capable of complete rolls with minimum roll rates defined in MIL-F-8785 to be 128 deg/s during combat phases and 69 deg/s during ground attack phases. The forebody of the configuration is shaped for signature reduction which may have an adverse affect on the flow field across the canopy. However, the flow field around the canopy is not known at this time.

2.2.4.2.2 Aircraft Operational Limits. The speed-altitude envelope of the configuration is shown in Figure 16. As stated before, this aircraft has the largest envelope of all the aircraft classes with exception to the hypersonic aircraft. The maximum dynamic pressure is limited to 2,100 psf. This results in a true supersonic capability of Mach 1.2 at sea level. The maximum speed limit at altitude is Mach 1.8 with the maximum altitude set at 55,000 ft. The loading limits are shown in Figure 17 and are similar to the air superiority limits. The maximum load factor is 9 and the minimum load factor is -4 at all speeds.



SKETCH NOT TO SCALE

Figure 15
Multi-Role Fighter (MRF) Configuration

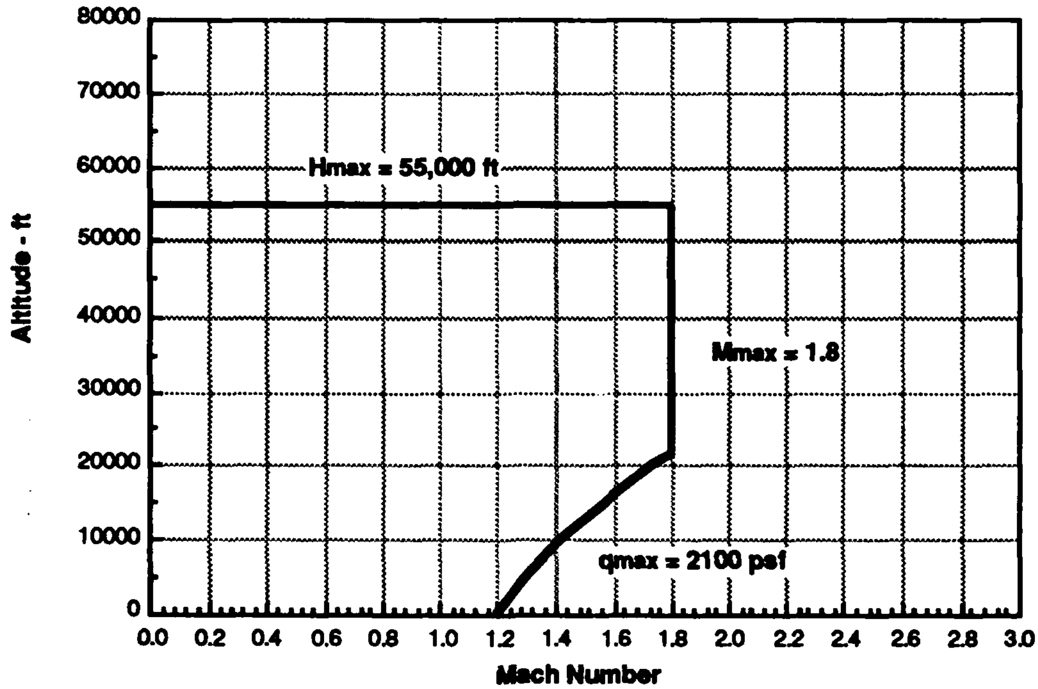


Figure 16
MRF Speed - Altitude Envelope

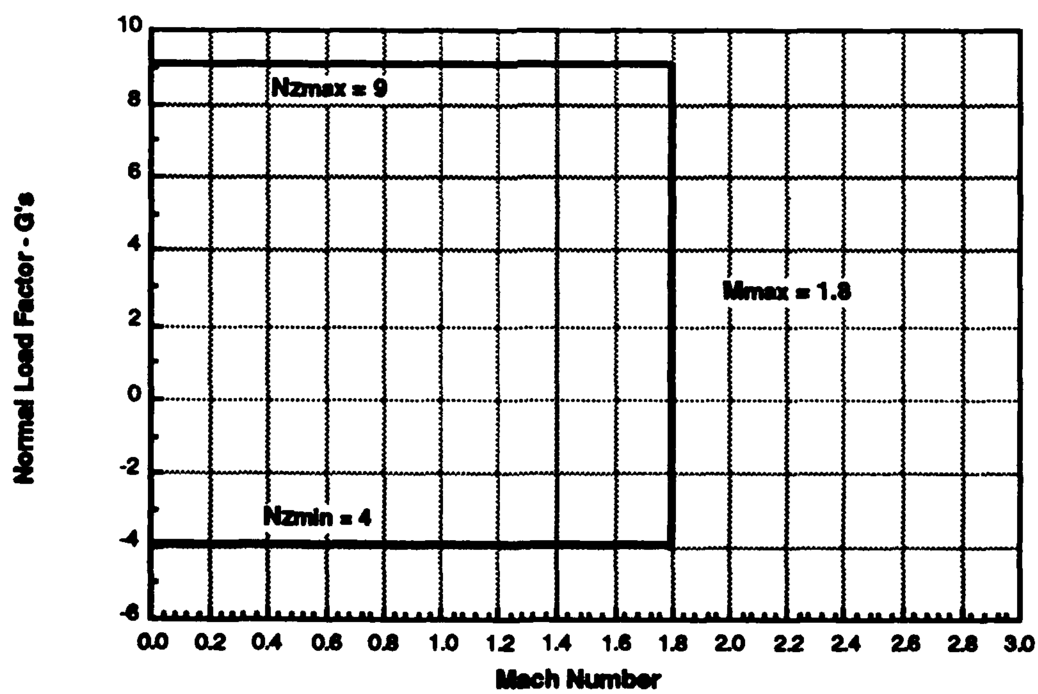


Figure 17
Limit Load Diagram for the MRF

2.2.4.2.3 Mission Profile Characteristics. One of the typical mission profiles for this configuration is shown in Figure 18. This is a battlefield interdiction mission which is a high-low-low-high profile. After takeoff, the aircraft climbs up to the cruise altitude and Mach number for best range. For this aircraft, the best cruise Mach and altitude are at Mach 0.9 between 30,000 and 40,000 ft depending on weight. At 50 nm from the target, the aircraft drops to the deck and penetrates at Mach 0.8 using terrain following to avoid detection. At the objective area, a ground attack is performed for an assumed 5 minutes duration. After the release of all of the stores, the vehicle egresses at low altitude at Mach 0.8. When out of the threat area, the aircraft then climbs and cruises back to the base at speeds and altitudes for maximum range. Upon arrival at the base, a 20 minute loiter is included for reserves.

Another of the typical mission profile is a combat air patrol mission (CAP) as shown in Figure 19. After takeoff, the vehicle climbs to 30,000 ft and best cruise speed. When the aircraft is 150 nm from the original base, the vehicle goes into loiter conditions for approximately 30 minutes. After the loiter, the vehicle accelerates to Mach 1.5 and engages the target for an assumed 2 minute duration. After the combat, the vehicle cruises back to the base at BCM and 30,000 ft. Upon arrival at the base, a 20 minute loiter is included for reserves.

The amount of flight time spent in each portion of the speed-altitude envelope is shown in Figure 20 for the battle field interdiction mission. The majority of the mission time is spent during the subsonic cruise legs which represent slightly over 60% of the mission time. The sum of the inbound and outbound climb legs total to less than 5% of the mission time. The penetration and combat phases of the mission represent approximately 15% of the mission time and is in a high threat area. Finally, the loiter leg represents slightly less than 20% of the mission time.

A breakdown of the combat air patrol mission time is shown in Figure 21. The climb and acceleration legs represent less than 5% of the mission time. The inbound and outbound cruise legs combine to represent slightly less than 45% of the mission time. The supersonic dash and combat legs only take up 5% of the mission time. The mid-mission loiter leg represents approximately 30% of the mission with the remaining time spent loitering at the base.

2.2.4.2.4 Operational Characteristics. The vehicle utilizes terrain following and terrain avoidance during the low altitude penetrations. As in the battle field interdiction mission, the speed for penetration is at Mach 0.8 or 530 knots. However, the vehicle is capable of Mach 1.2 on the deck which is near 800 knots. The altitude for terrain following is assumed to be at 200 ft for the subsonic penetration. However, it is not known whether this is the minimum altitude required for supersonic speeds. During maximum weight takeoffs, the aircraft should lift off at 142 knots and pass the obstacle at 154 knots. The landing weight is assumed to be maximum weight without 80% of the fuel. For this weight, the vehicle passes over the obstacle slightly over 120 knots and touches down at 110 knots.

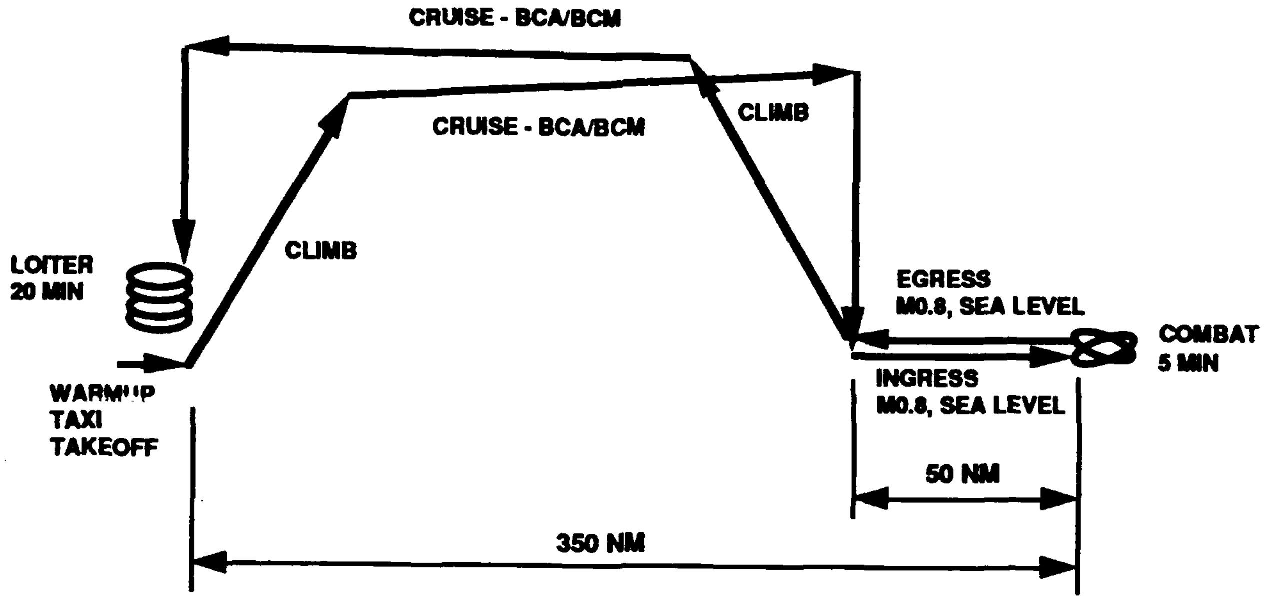


Figure 18
Battle Field Interdiction Mission for the MRF

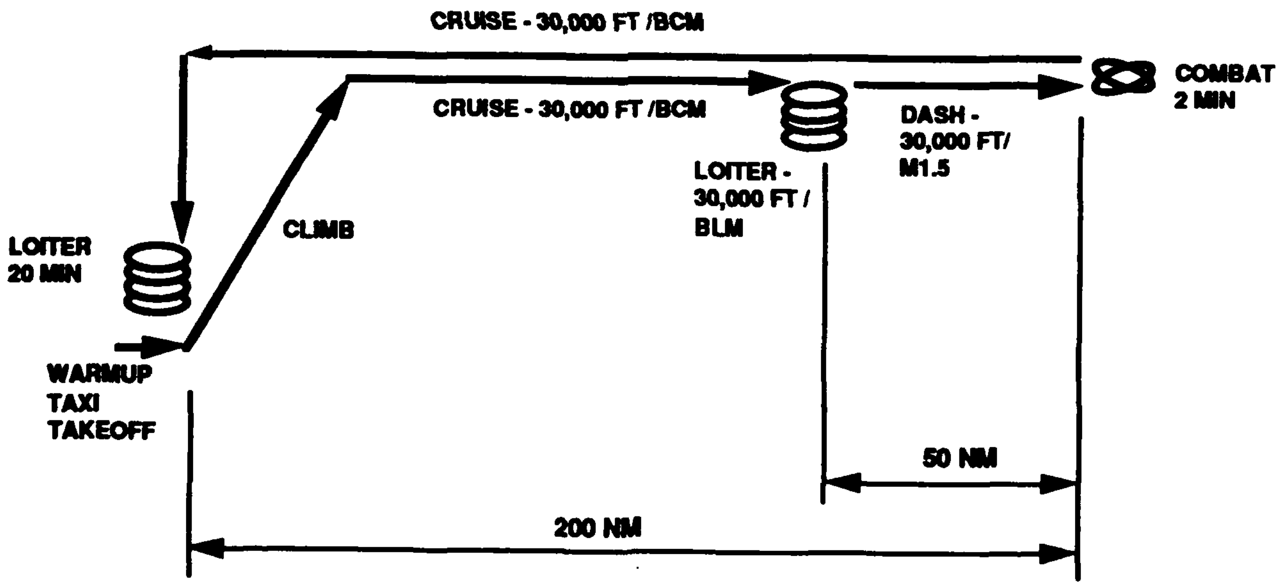


Figure 19
Combat Air Patrol Mission for the MRF

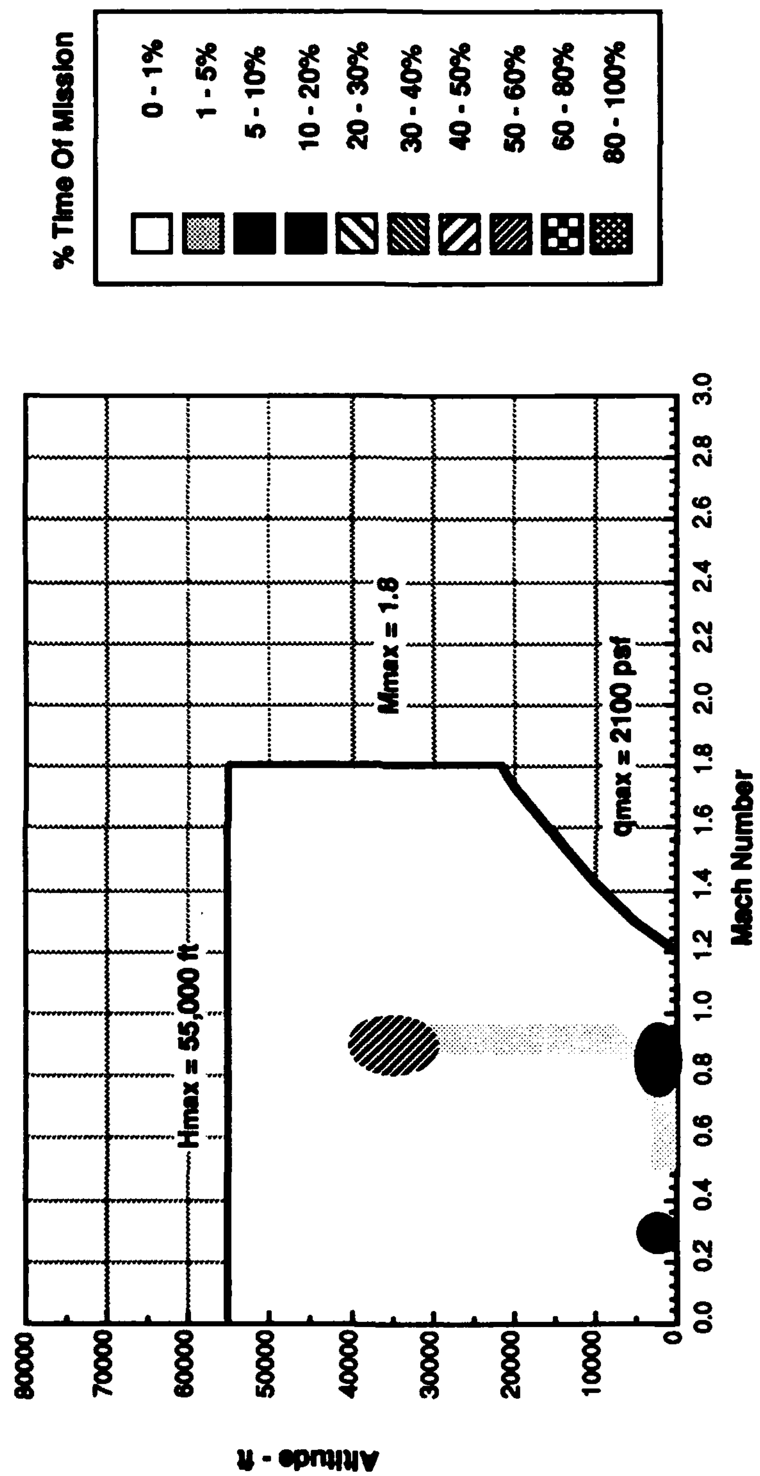


Figure 20
Battle Field Interdiction Mission Flight Time Breakdown

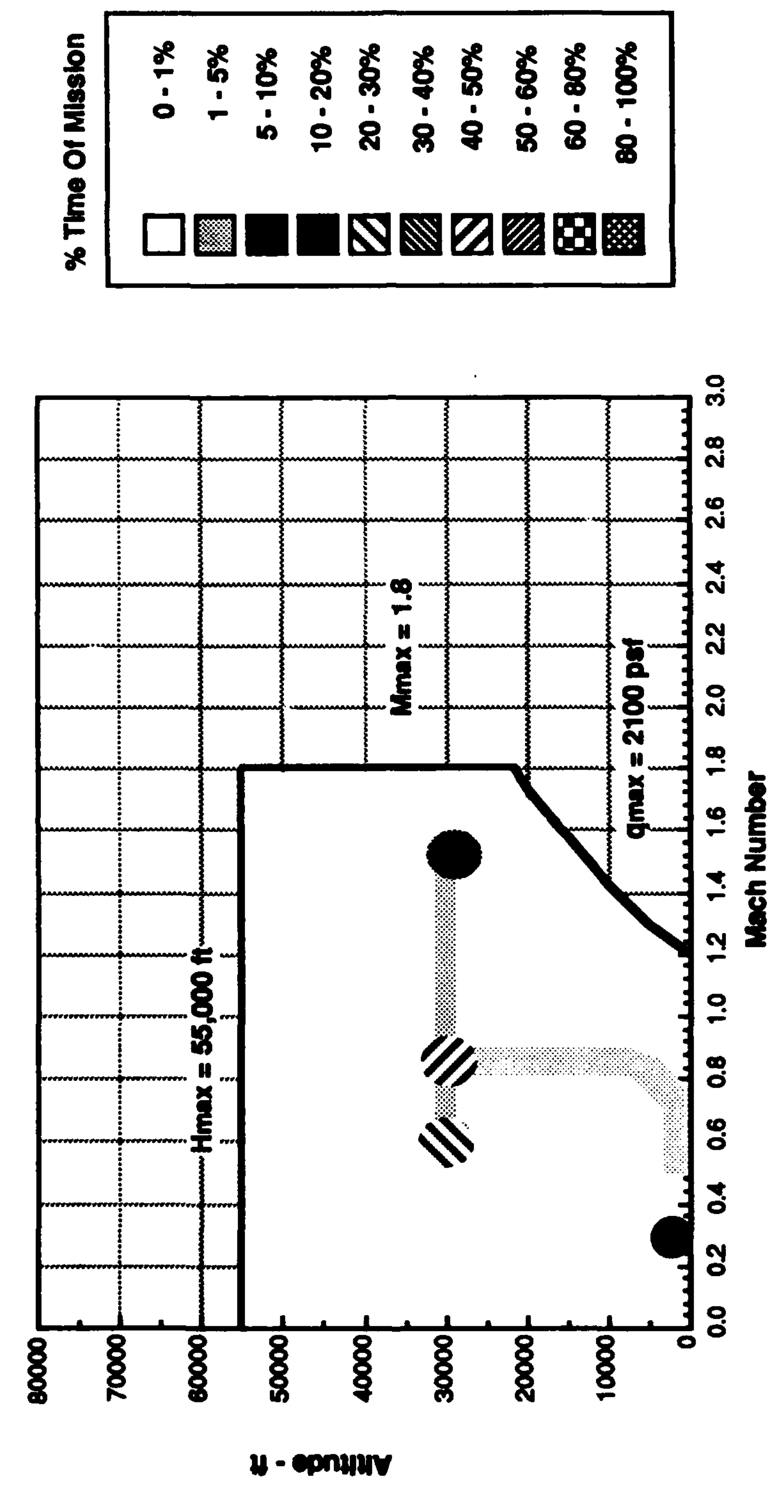


Figure 21
Combat Air Patrol Mission Flight Time Breakdown

2.2.4.3 Close Air Support

2.2.4.3.1 Configuration Dependent Parameters. There has been recent debate on future requirements for close air support (CAS) aircraft. It is proposed that CAS must have increased speed for survival. General Dynamics has taken this position by proposing their F-16 to meet the CAS mission. However, the durable A-10 showed that a lower speed aircraft can meet the CAS mission in Operation Desert Storm. The requirements that were used on this study is for a purely subsonic aircraft. The configuration is shown in Figure 22. The aircraft uses twin engines with thrust vectoring for pitch control. The two man crew aircraft is capable of TF/TA and night / all-weather operations. The missions that this aircraft can perform are typically at low altitudes.

During the ground attack, the aircraft must be very maneuverable. However, this aircraft did not relax the static stability as was done in the previous two fighters. The static stability goals were set to be between 2.5% to 5% stable. A two dimensional thrust vectoring system is used to enhance longitudinal maneuvering and downward facing canards are used to enhance lateral maneuvering. As with the previous two aircraft, some limited amount of post stall capability is gained with the thrust vectoring. The downward facing canards allow for flat turns increasing the typical yaw limits of the aircraft. The configuration is capable of 360 degree rolls at rates defined in MIL-F-8785 to be 69 deg/s during ground attack phases. The forebody is conventional with the exception of the downward canards. However, these canards are not expected to influence the flow field around the canopy except at high angles of attack.

2.2.4.3.2 Aircraft Operational Limits. The speed-altitude envelope of the configuration is shown in Figure 23. Because this is a subsonic aircraft, the speed limit of this configuration is near Mach 0.9. The maximum dynamic pressure is 1,000 psf and the maximum altitude is 40,000 ft. Most of the mission will be spent in the lower right hand corner of the envelope with high penetration speeds at low altitudes. The load limits are shown in Figure 24. During the ground attacks, the aircraft must be very maneuverable. This sets the maximum load factor to 7.5 and the minimum load factor to -3.

2.2.4.3.3 Mission Profile Characteristics. The close air support mission is shown in Figure 25. After takeoff, the aircraft accelerates to 500 knots and goes immediately into TF/TA operations. Once the aircraft reaches the target area, an assumed 5 minute ground attack occurs. During this attack the aircraft must have good sustained turn performance and be able to pop-up to approximately 4,000 ft with little loss in energy. After the weapons release, the aircraft then returns to base at 500 knots using TF/TA maneuvers. At the base, a 20 minute loiter is included for reserves.

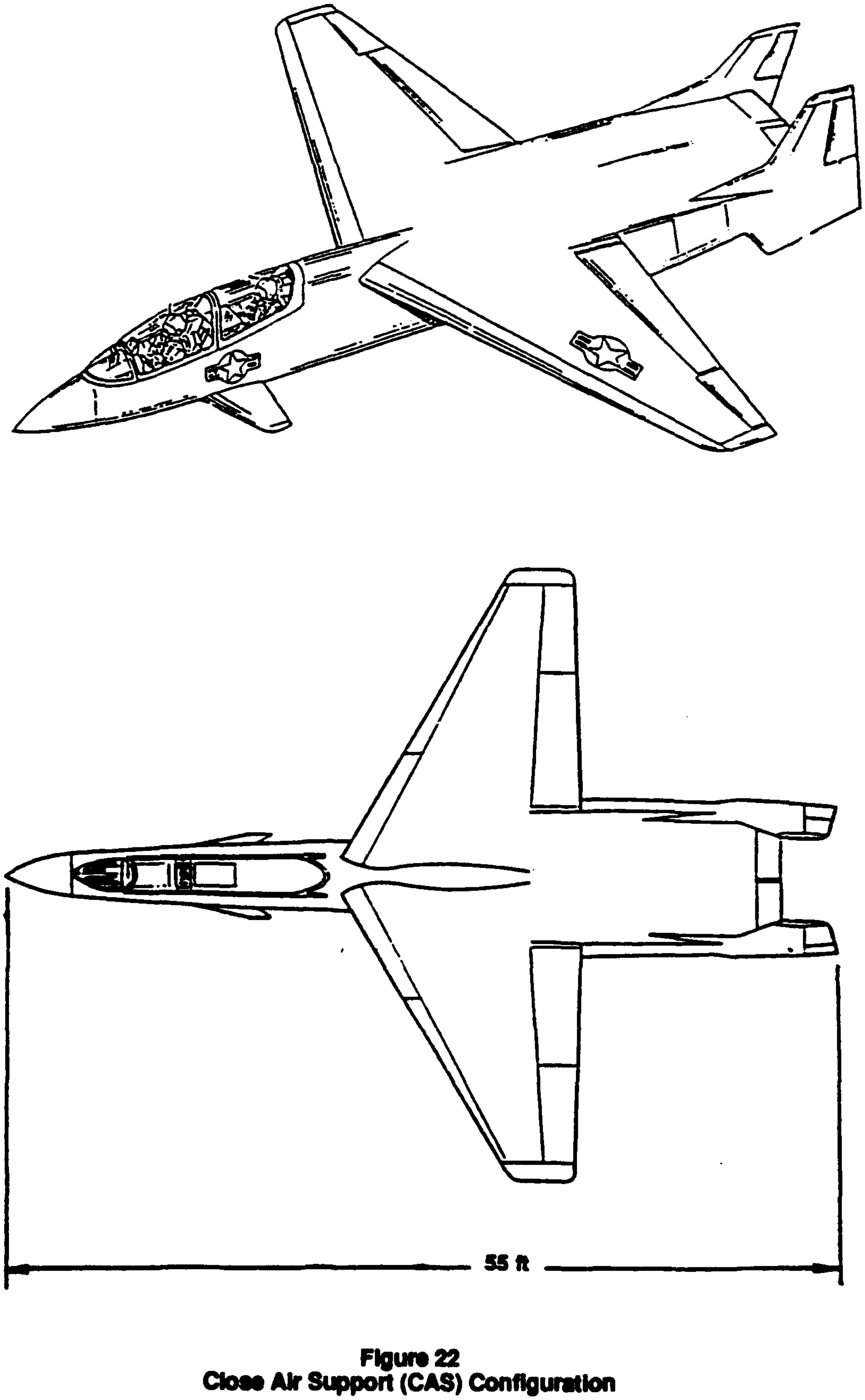


Figure 22
Close Air Support (CAS) Configuration

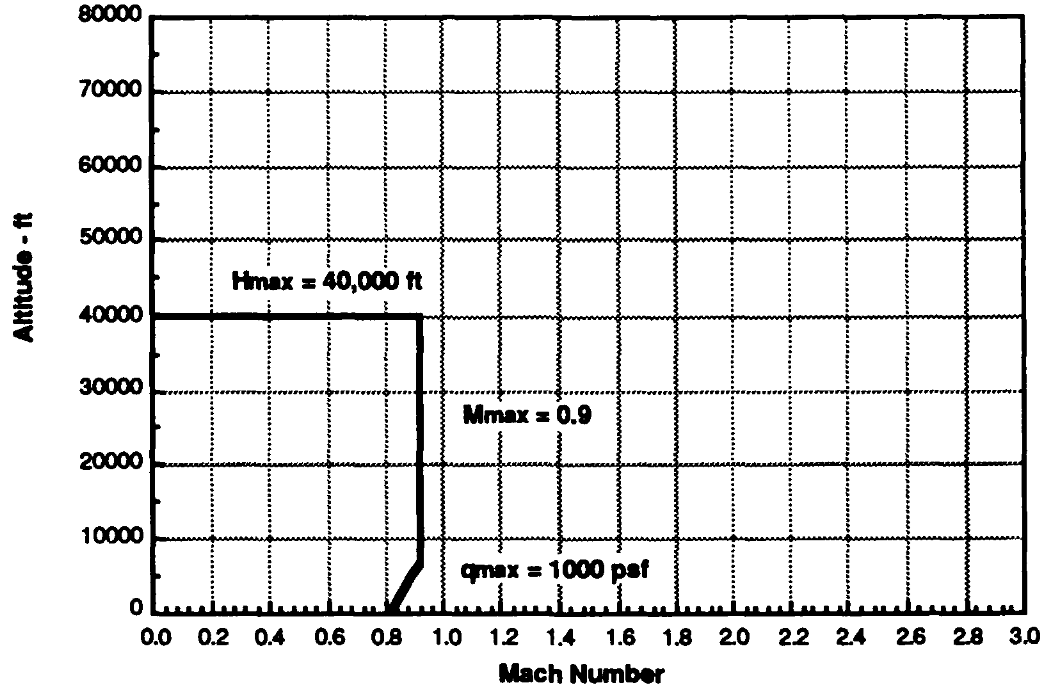


Figure 23
CAS Speed - Altitude Envelope

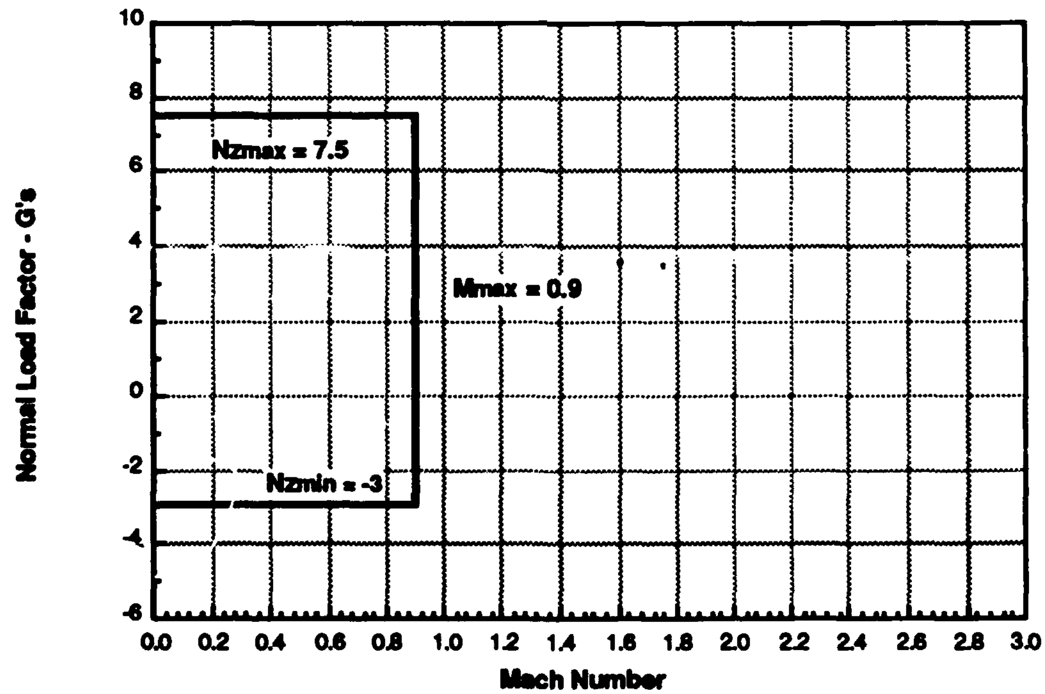


Figure 24
Limit Load Diagram for the CAS Aircraft

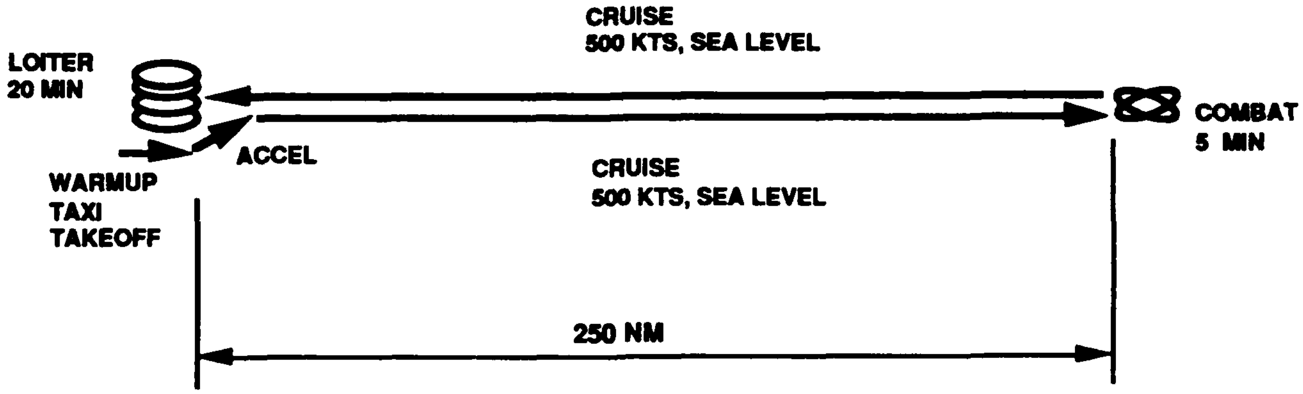


Figure 25
Close Air Support Design Mission

This aircraft can also perform high-low-low-high missions as shown in Figure 26 After takeoff the aircraft climbs up to the cruise altitude and Mach number for best range. For this aircraft, the best cruise Mach and altitude are at Mach 0.8 between 25,000 and 30,000 ft depending on weight. At 100 nm from the target area, the aircraft descends to the deck and loiters. For this aircraft, the maximum loiter time is approximately 80 minutes. After loiter, the aircraft penetrates at 500 knots at low altitude using terrain following to avoid detection. At the objective area, a ground attack is performed for an assumed 5 minutes duration. After the release of all of the stores, the vehicle egresses at low altitude at 500 knots. When out of the threat area, the aircraft then climbs and cruises back to the base at speeds and altitudes for maximum range. Upon arrival at the base, a 20 minute loiter is included for reserves.

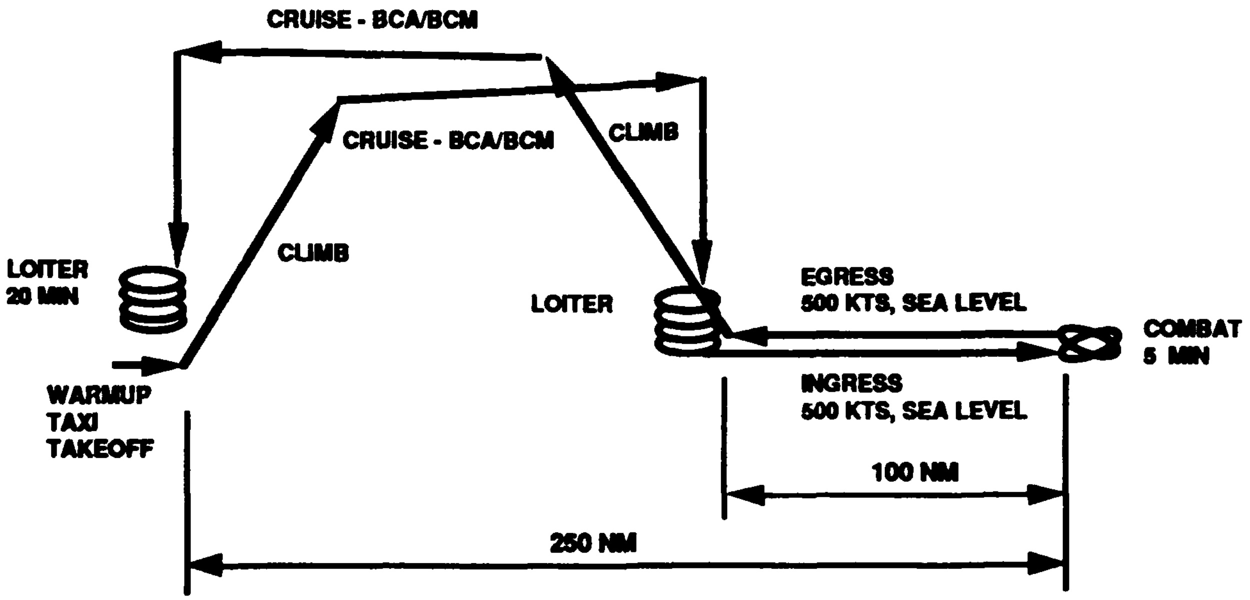


Figure 26
High-Low-Low-High With Loiter Mission Profile

As can be seen in Figure 27, the majority of the time that is spent in the CAS mission is at the bottom right hand corner of the flight envelope. About 75% of the mission is performed at 500 knots at low altitudes. The only other significant amount of mission flight time is spent to loiter which takes up the other 25%.

For the high-low-low-high mission, the flight envelope is more filled out, Figure 28. The high altitude cruise legs and the low altitude penetration legs each account for slightly less than 20% of the mission flight time. The majority of the time is spent in the loiter condition approaching 60% of the mission time. The time to climb and accelerate makes up less than 5% of the mission time.

2.2.4.2.4 Operational Characteristics. The vehicle utilizes terrain following and terrain avoidance for all of the CAS mission and during the low altitude penetrations for the high-low-low-high mission. The penetration speed is predicted to be at 500 knots and at altitudes between 75 to 200 ft above ground level. The dive angles and velocities during the attack are not known for the ground attack phase but are assumed to be similar to the A-10. During maximum weight takeoffs, the aircraft lifts off at 115 knots and pass the obstacle at 125 knots. The landing weight is assumed to be without payload and without 80% of the fuel. For this weight, the vehicle passes over the obstacle at 95 knots and touches down at 85 knots.

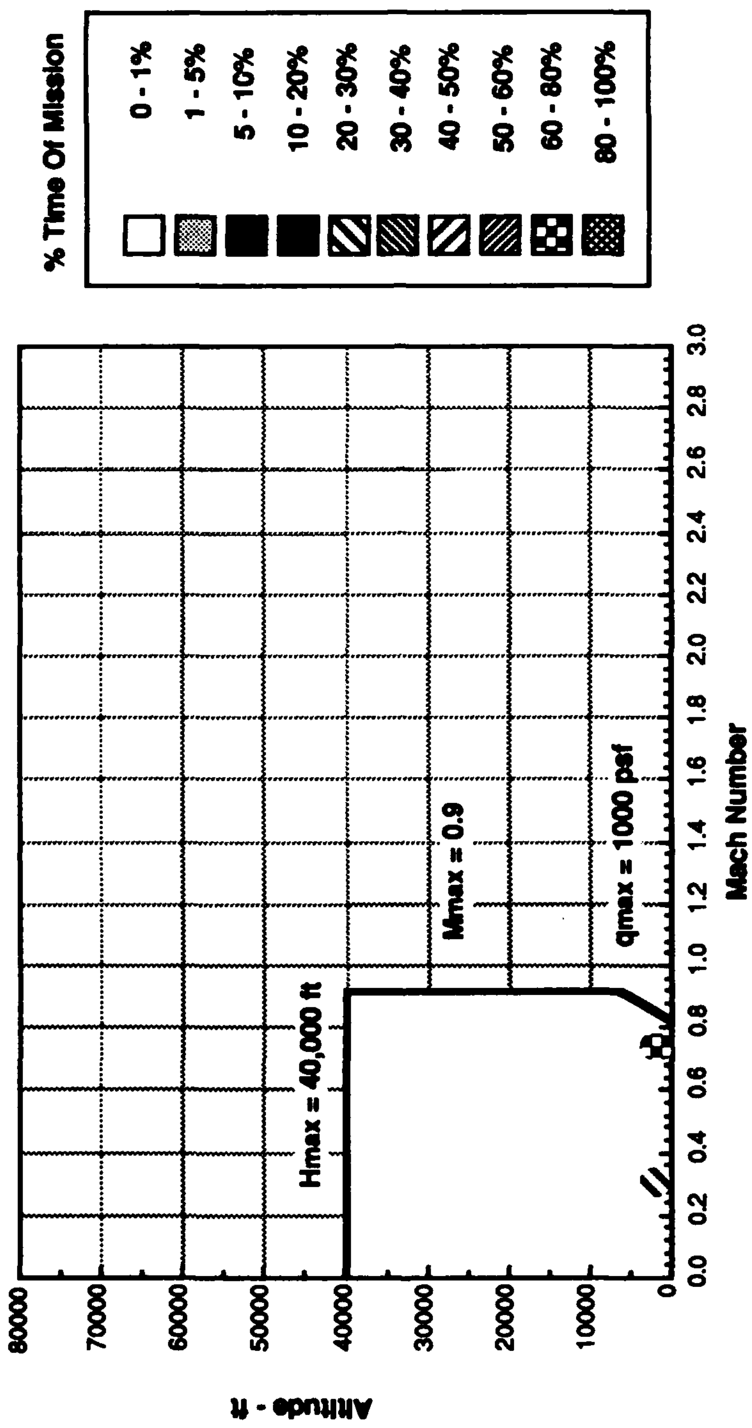


Figure 27
CAS Mission Flight Time Breakdown

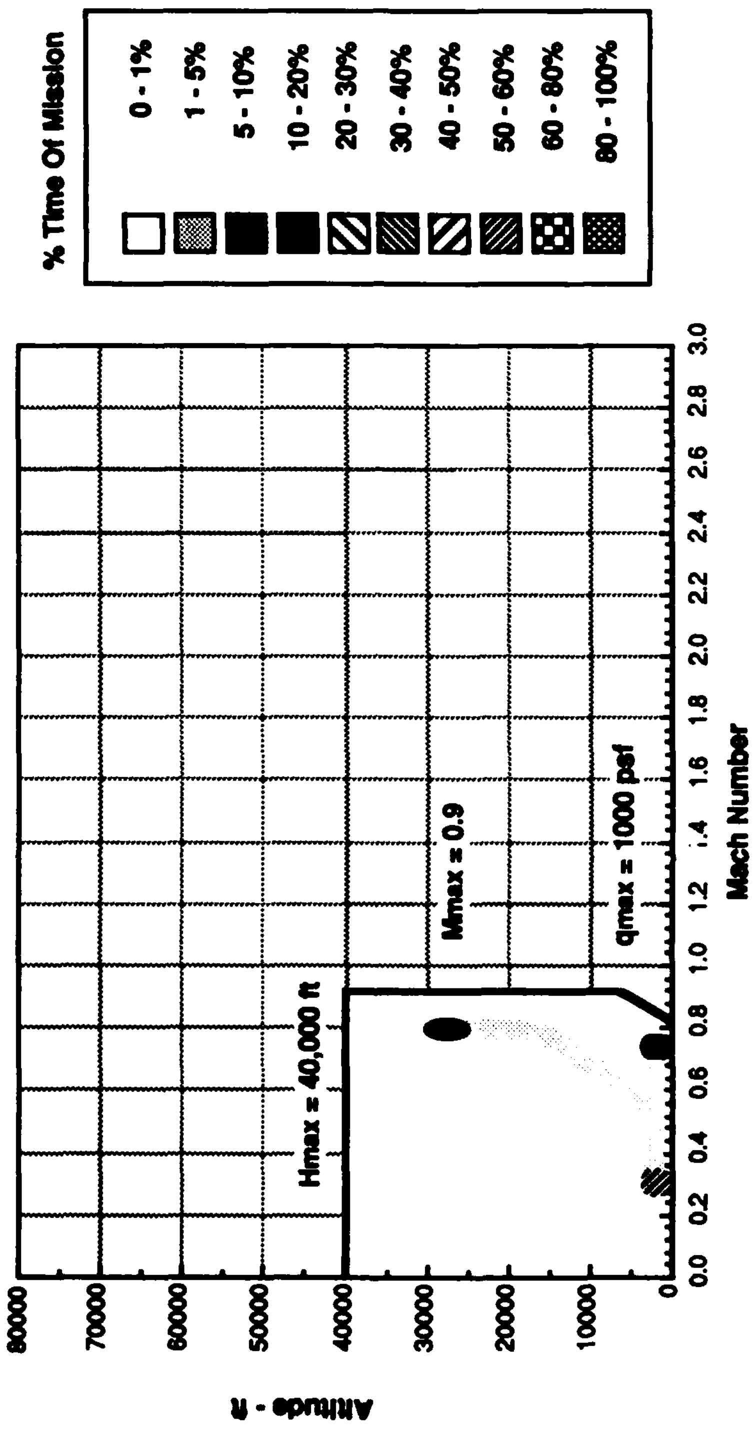


Figure 28
High-Low-Low-High Mission Flight Time Breakdown

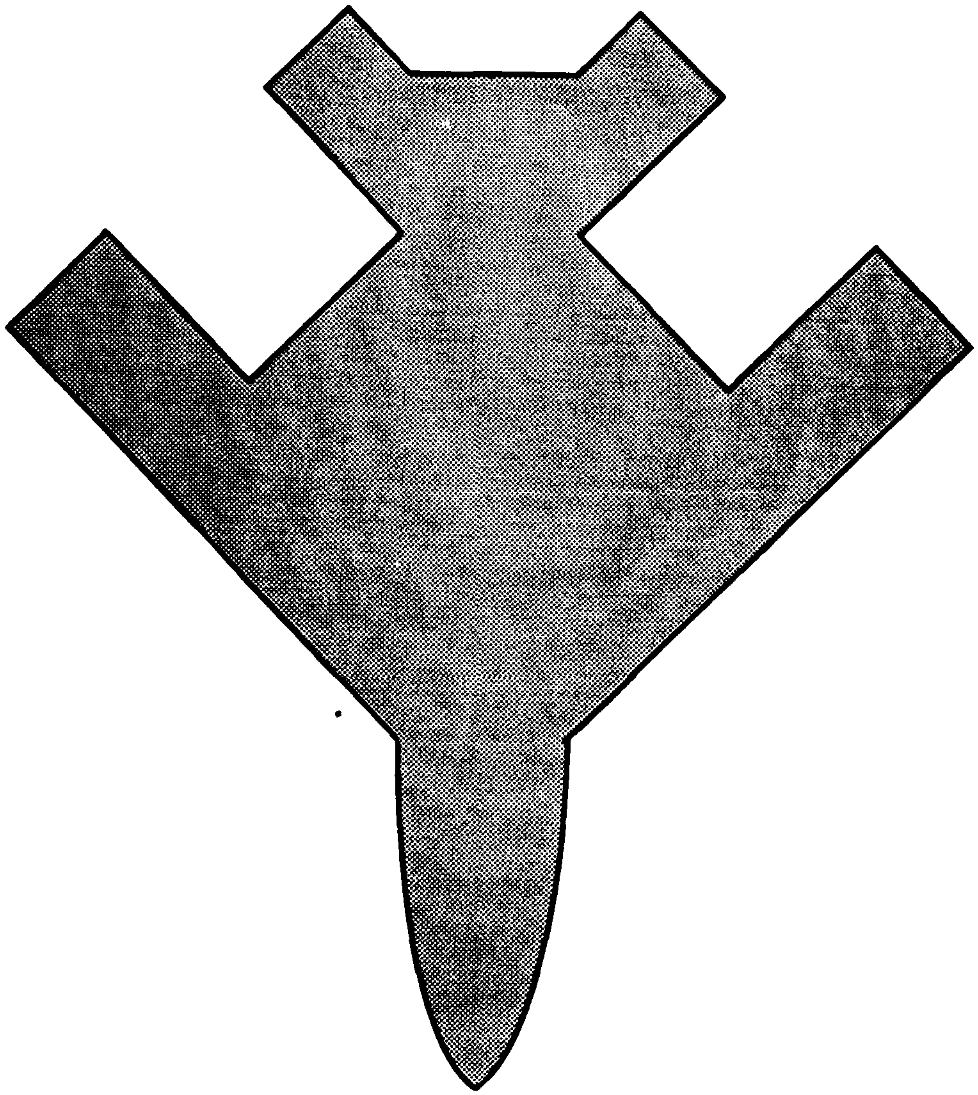
2.2.4.4 Attack

2.2.4.4.1 Configuration Dependent Parameters. The Navy has stated that the need for an A-6 replacement is critical. With the cancellation of the A-12, a new A-X proposal has been released. This configuration is unique because of the limitations imposed by operations from an aircraft carrier. The configuration used in this study is shown in Figure 29. This twin engine configuration utilizes variable sweep to meet the various mission requirements. During supersonic operations and low altitude penetrations, the wings are swept aft for good aerodynamic performance. During catapult launches and carrier arrests, the wings are swept forward for increased lift. During storage on the aircraft deck, space is severely limited requiring the aircraft to fold the wings to be parallel to the fuselage reference line.

During ground attacks, the maneuver capability of the aircraft must be high. The approach used to meet the maneuverability requirements were the same as the CAS aircraft. The static stability goals were set to be between 2.5% and 5% stable. In addition, a two dimensional thrust vectoring system is used which may allow some post stall operations. The aircraft can make 360 degree rolls at a minimum rate of 69 deg/s defined in MIL-F-8785 for combat phases. The forebody has little low observable shaping and is not expected to have an adverse flow field around the canopy.

2.2.4.4.2 Aircraft Operational Limits. The speed-altitude envelope of the configuration is shown in Figure 30. The maximum dynamic pressure is slightly under 1,500 psf which defines the maximum allowable speed at sea level to be at sonic conditions. The maximum speed limit at altitude is Mach 1.6 with the maximum altitude set at 50,000 ft. The loading limits are shown in Figure 31. The maximum load factor is 7 and the minimum load factor is set to -3. Both the speed-altitude limits and the load limits are set from the mission requirements.

2.2.4.4.3 Mission Profile Characteristics. One of the typical mission profiles for this configuration is shown in Figure 32. This Naval attack mission is a high-low-low-high altitude profile. After launch from the carrier, the aircraft climbs up to the cruise altitude and Mach number for best range. For this aircraft, the best cruise Mach and altitude are at Mach 0.9 between 40,000 and 50,000 ft depending on weight. At 100 nm from the target, the aircraft drops to the deck and penetrates at Mach 0.9 to the objective point. At the objective area, the vehicle attacks the target for an assumed 2 minutes duration. After the release of all of the stores, the vehicle egresses at low altitude at Mach 0.9. When out of the threat area, the aircraft then climbs and cruises back to the base at speeds and altitudes for maximum range. For reserves, the aircraft arrests on the carrier with 4,000 lbs of fuel.



SKETCH NOT TO SCALE

Figure 29
Attack Aircraft Concept

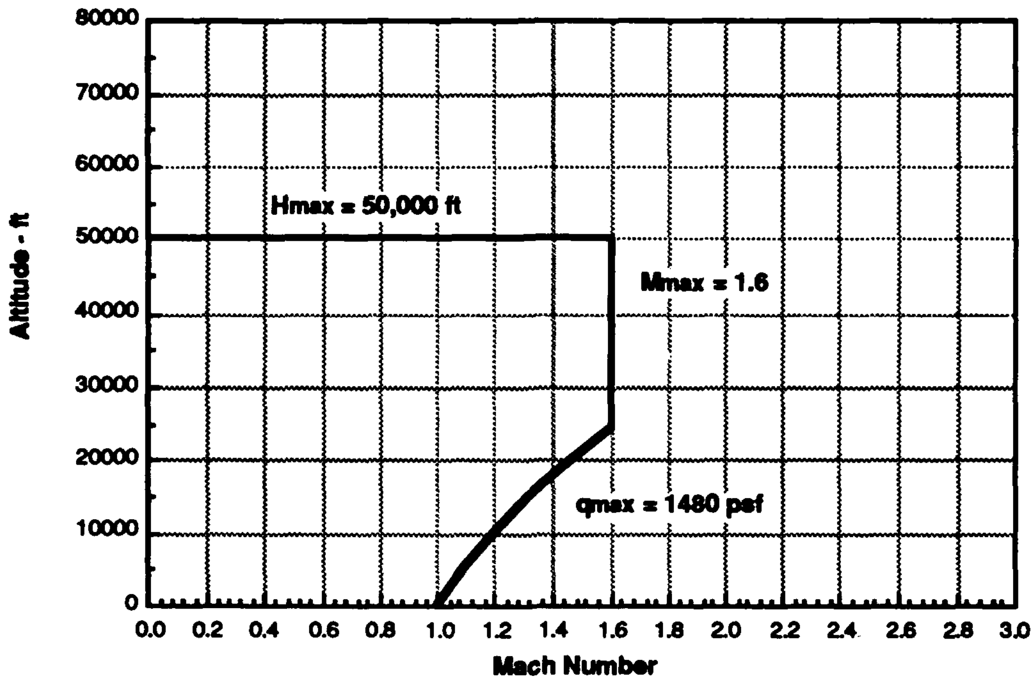


Figure 30
Speed - Altitude Limit Diagram for Attack Missions

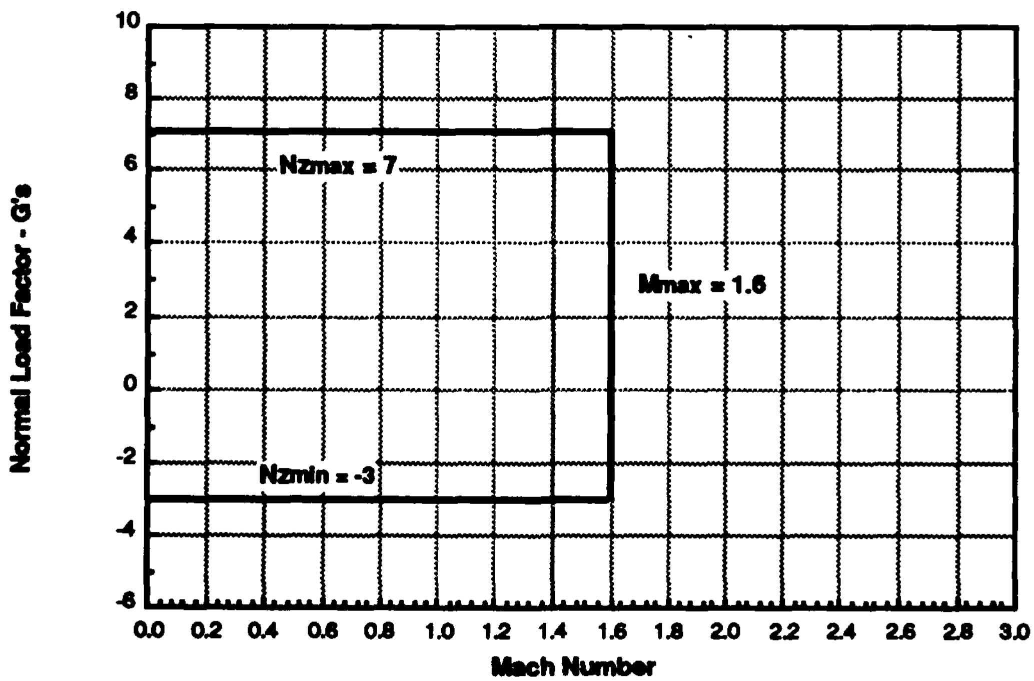


Figure 31
Limit Load Diagram for Attack Missions

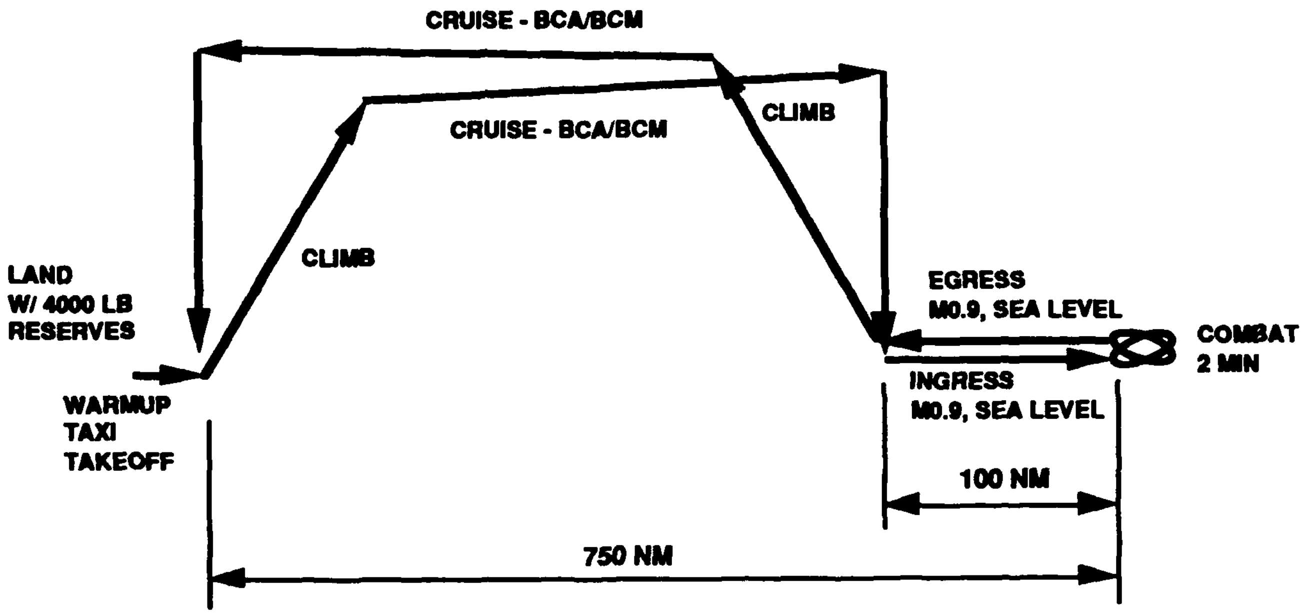


Figure 32
Naval Attack Mission Profile

The amount of flight time spent in each portion of the speed-altitude envelope is shown in Figure 33. The majority of the mission is spent in the cruise legs representing approximately 80% of the flight time. Less than 20% of the mission time is spent at low altitude operations The climb leg makes up represents less than 5% of the mission time. For other high altitude attack mission profiles, the supersonic capability will be used filling in the upper right hand of the flight envelope.

2.2.4.4.4 Operational Characteristics. The majority of the attack missions include low altitude operations. The terrain following requirements are not as stringent as for the CAS aircraft except in operations over land. The penetration speed is high at Mach 0.9 which corresponds to 595 knots. The altitude for the low altitude penetration is yet to be defined but is expected to be near 200 ft above ground level (AGL). The dive angles and velocities during the attack are not known for the ground attack phase but are assumed to be similar to the A-6. During maximum weight takeoffs from land, the aircraft lifts off at 185 knots and pass the obstacle at 200 knots. The landing weight is assumed to be without 80% of the fuel. For ground landings at this weight, the vehicle passes over the obstacle at 124 knots and touches down at 113 knots. For carrier launches at maximum weight, the catapult end speed is 132 knots for a C13-1 catapult. For arrested landings, the maximum allowable approach speed is 134 knots for a MK7-Mod3 arresting engine.

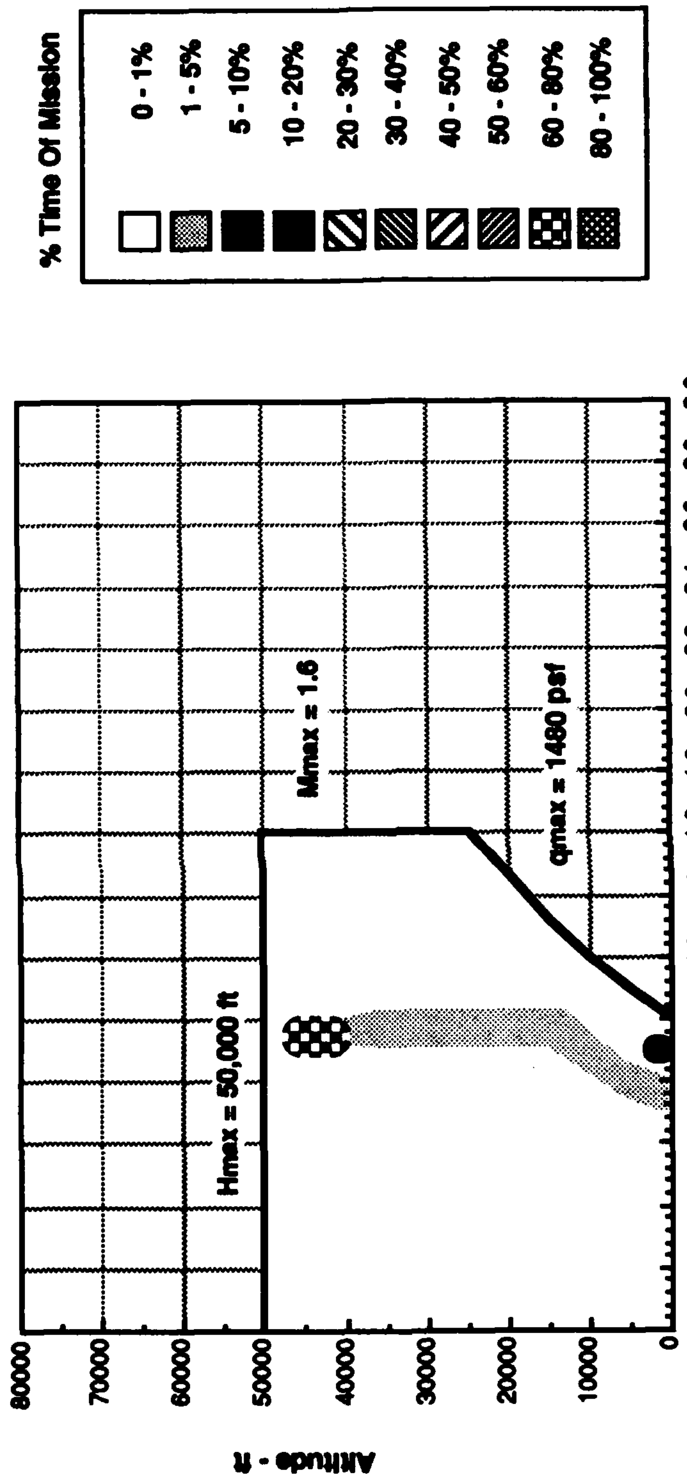


Figure 33
Naval Attack Mission Flight Breakdown

2.2.4.5 Primary Trainer

2.2.4.5.1 Configuration Dependent Parameters. For a primary training system, the design is very conventional. As shown in Figure 34 the configuration is a conventional wing body with a two man crew. Bifurcated inlets feed air into the single engine. The flight envelope is limited to lower speeds at all altitudes, but the aircraft can still pull 7g's.

The configuration is assumed to be very stable, probably near 5%. Pitch is limited to conventional stall angles and the configuration is capable of 360 degree rolls. The minimum roll rates are defined in MIL-F-8785 to be 46 deg/s for the most stringent operations. The flow field should be favorable around the canopy due to the conventional design.

2.2.4.5.2 Aircraft Operational Limits. The speed-altitude envelope for the training system is smaller than all of the other classes of aircraft, Figure 35. The maximum dynamic pressure is very low at 300 psf. This limits the aircraft to less than 300 knots on the deck. The maximum Mach number is 0.7 which corresponds to 400 knots at altitude. The altitude is limited to 45,000 ft. The loading limits are still substantial as shown in Figure 36. The maximum load factor is 7 and the minimum load factor is set to -3. The higher load factors allow the student pilot to perform realistic military maneuvers while at slower and safer speeds.

2.2.4.5.3 Mission Profile Characteristics. Although there are several training missions, the mission shown in Figure 37 is for formation flying. After takeoff, the aircraft climbs up to the preset cruise altitude of 15,000 ft. After 10 minutes of cruise, area work is performed. This area work consists of formation flying including trails (close and extended), rejoins and echelons. All of the area work is limited to altitudes between 6,000 ft and 22,000 ft. After the area work is complete, formation approaches or VFR pattern work is performed for 5 minutes. Typical fuel reserves include enough fuel for a 250 nm alternate divert capability and 10% of total mission fuel.

The majority of the mission is spent performing area work, Figure 38. Approximately 70% of the mission flight time is dedicated to formation flying and 8% of the flight time dedicated to approach work. The climb portion of the mission takes another 8% of the mission flight time and the 10 minute cruise takes up the last 16% of the flight time.

2.2.4.5.4 Operational Characteristics. For a primary training system, the first priority is safety. The speeds are very slow and low altitude operations are avoided. Takeoff and landing speeds are slow when compared to the other aircraft. For takeoff, the training system can lift off at 90 knots and pass over the obstacle at 98 knots. Assuming 80% of the fuel out for landing, the obstacle speed is 56 knots and the touchdown speed id 53 knots.

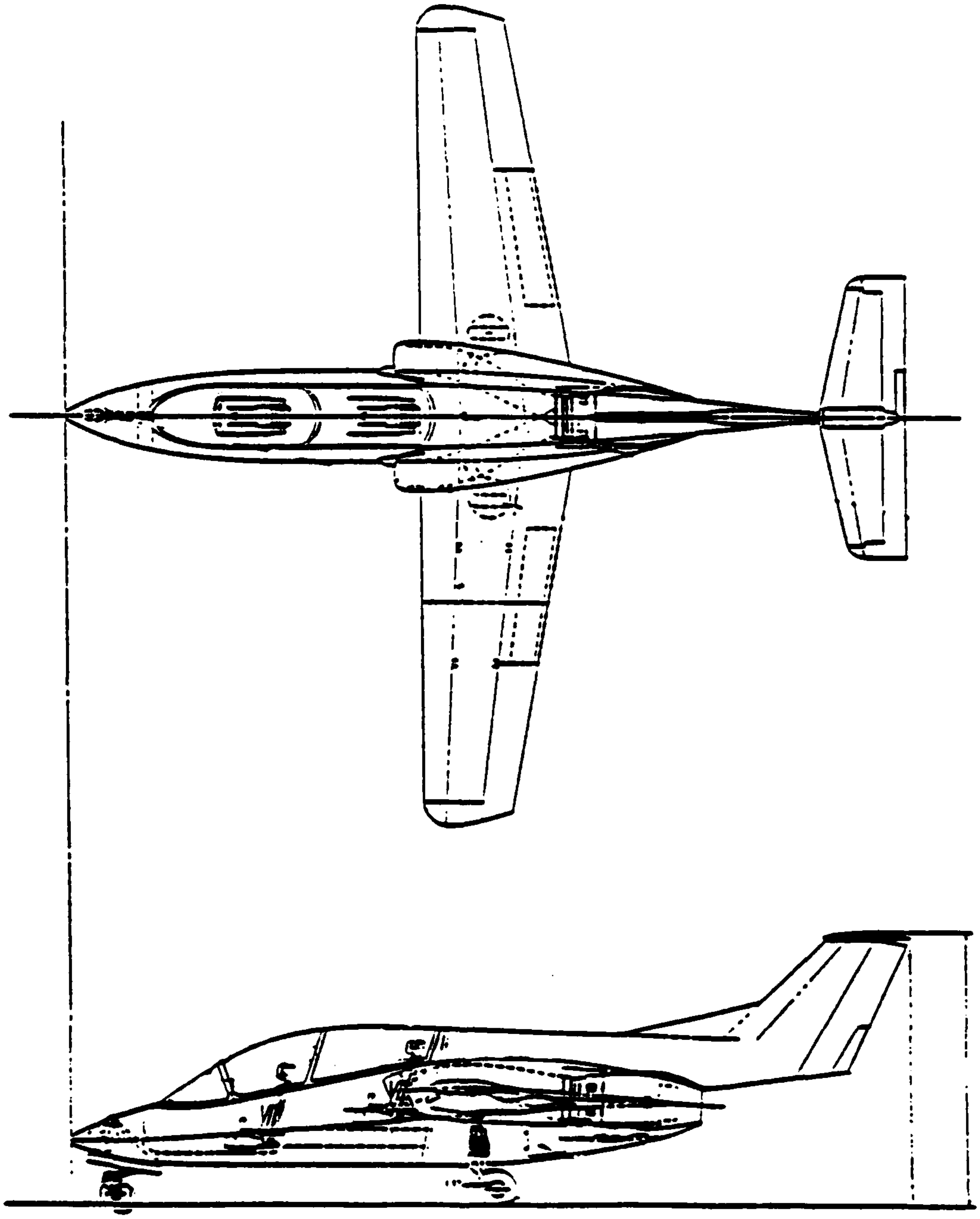


Figure 34
Primary Aircraft Training System (PATS)

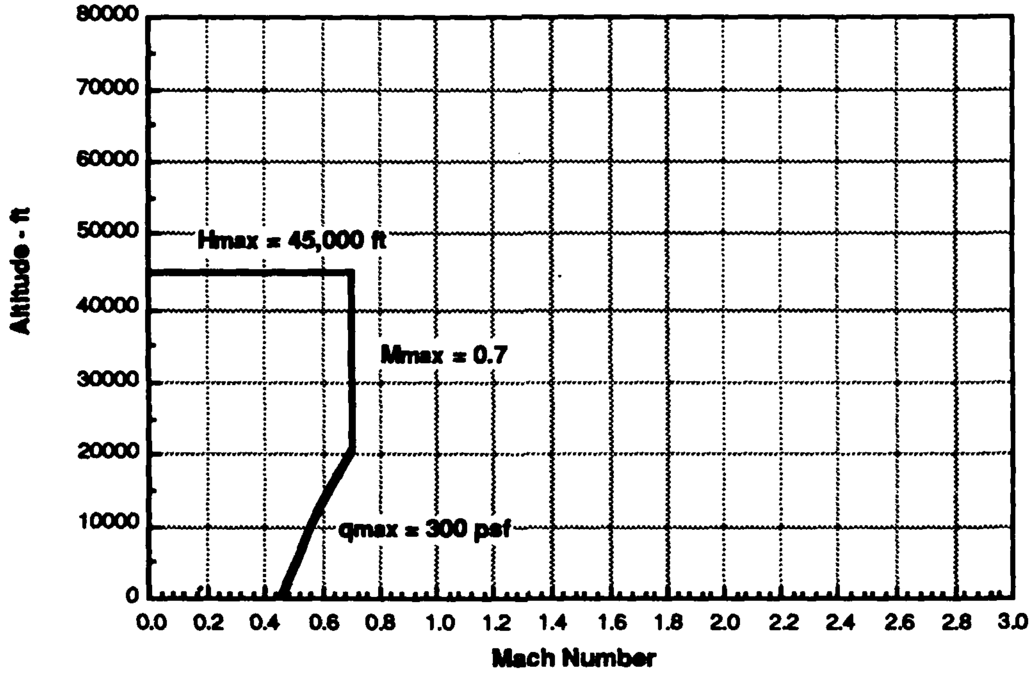


Figure 35
PATS Speed - Altitude Envelope

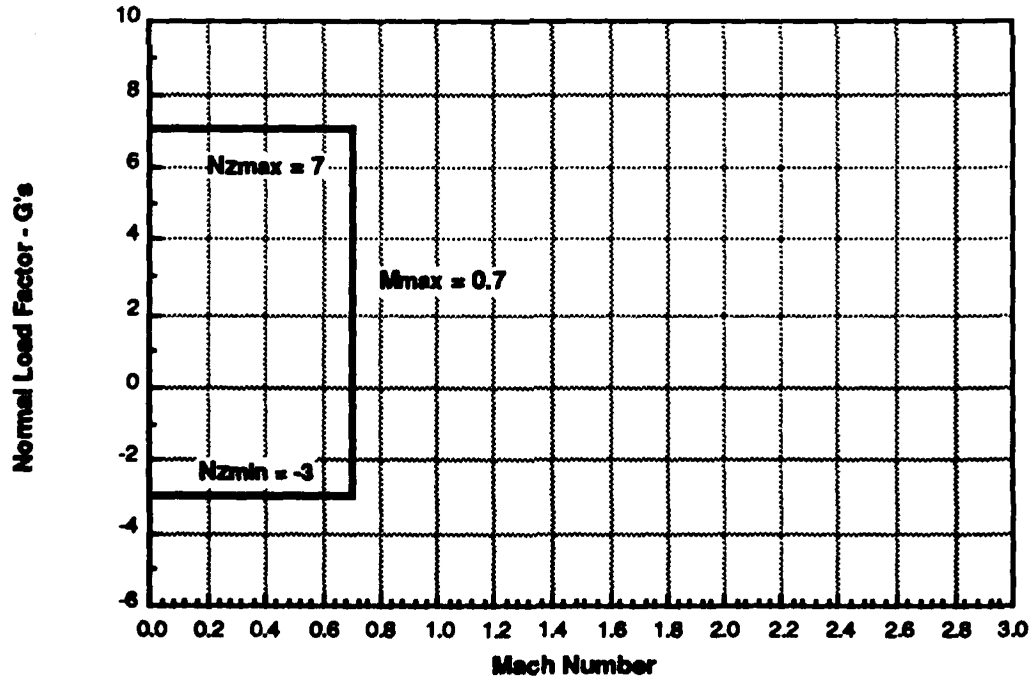


Figure 36
PATS Limit Load Diagram

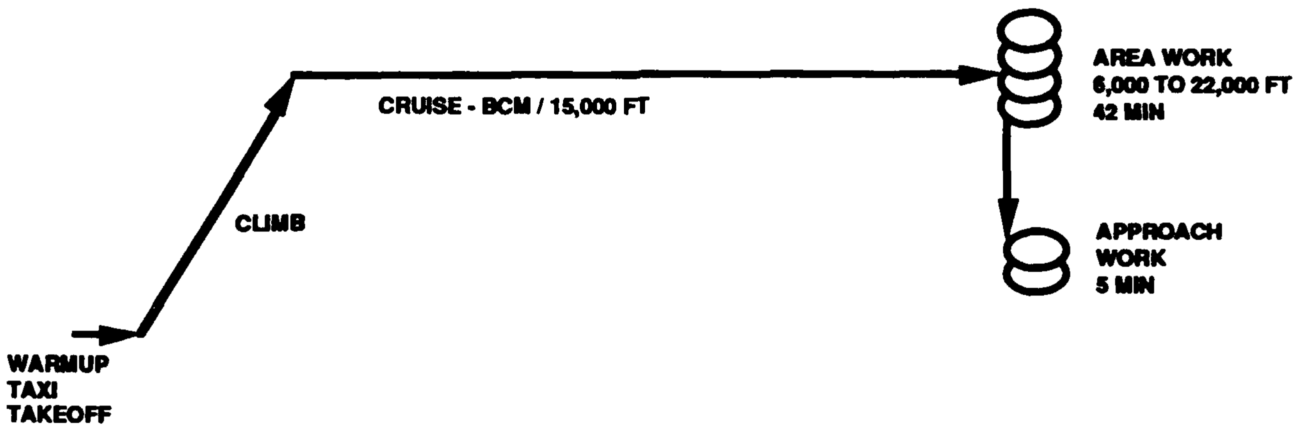


Figure 37
Formation Flying Mission Profile

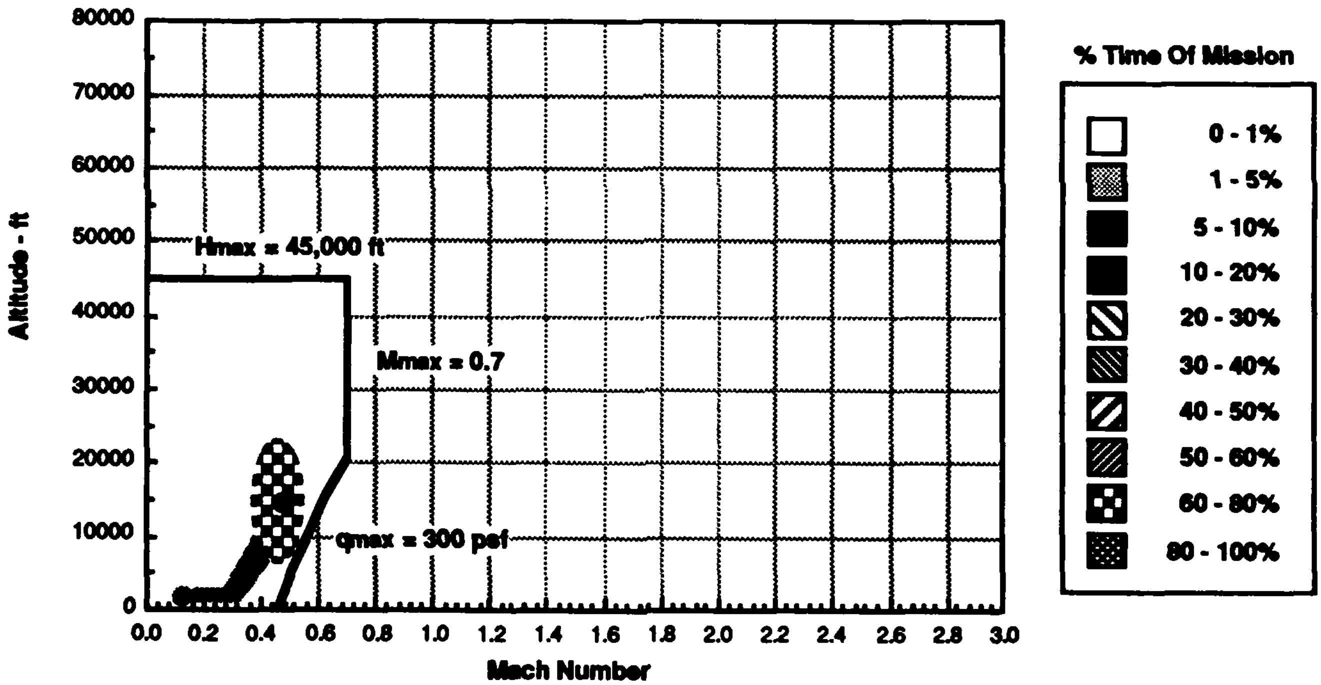


Figure 38
Formation Training Mission Flight Breakdown

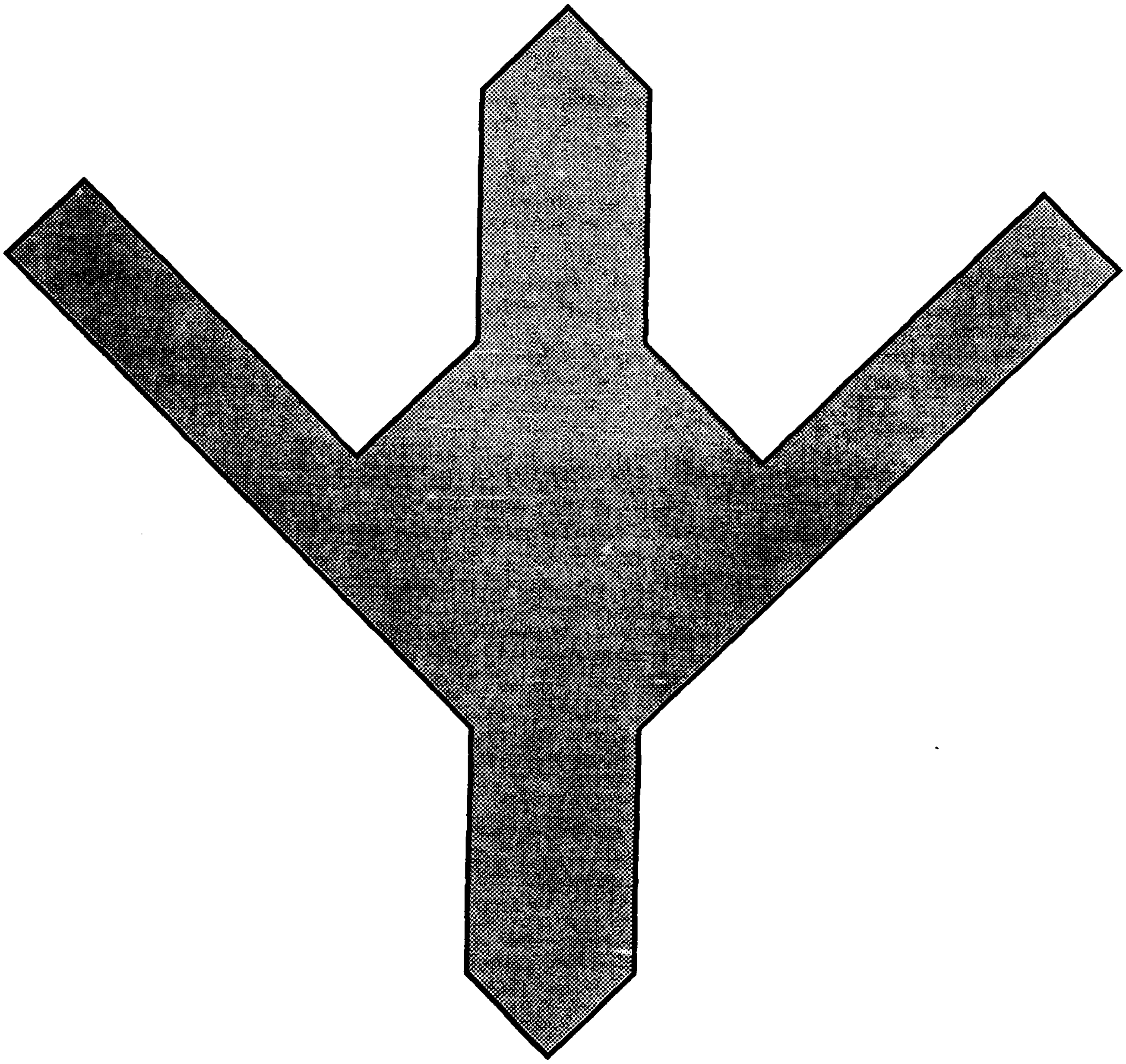
2.2.4.6 Strategic Bomber

2.2.4.6.1 Configuration Dependent Parameters. The requirements for future strategic bombers are evolving. The 1950's B-52 bomber is still in service and performs its mission at high altitudes and subsonic speeds. These slow speeds and very high signature levels leaves the B-52 vulnerable to attack. In the 1960's, hypersonics were investigated with the proposed XB-70 aircraft which used wave riding technologies to efficiently cruise at speeds near Mach 3.0. These speeds were reduced to supersonic levels with the development of the B-1A bomber after the cancellation of the B-70. However, after the B-1A was cancelled, the new B-1B aircraft was developed as a subsonic aircraft. To increase the survivability of the B-1B, the aircraft penetrates at Mach 0.85 and 200 ft AGL. Operations at this low altitude is not very fuel efficient and potentially dangerous. The B-2 tried to eliminate low altitude operations by integrating a low observable shape into a flying wing configuration. Although the B-2 was designed as a high flying configuration, developments in radar are expected to force the B-2 into flying at low altitudes in very high threat scenarios. The B-2 is expected to penetrate at Mach numbers near 0.7 which is approximately 100 knots slower than the B-1B. The newest trend is seen in this study with speed and stealth integrated into a design that can perform a true all high altitude mission.

The proposed aircraft is shown in Figure 39. It is a multi-engine configuration with a very slender body. The higher sweep and the slender body allow the configuration to go supersonically. As will be shown latter, the maximum dynamic pressure is low eliminating high subsonic penetrations at low altitudes. Therefore, the configuration is basically limited to high altitude operations over high threat areas.

This is one of the few configurations that maneuver requirements are not a driver. However, the stability level is relaxed so that the trim drag can be reduced. Goal stability levels of this configuration is for 4% unstable. Thrust vectoring is not used on this aircraft and is limited to conventional stall margins. Roll limits are yet to be defined. The B-1B is capable of 360 degree rolls where as the B-2 is postulated to not have this capability. Minimum roll rates are defined in MIL-F-8785 to be 20 deg/s. The forebody is shaped for signature reduction which may degrade the flow field around the canopy.

2.2.4.6.2 Aircraft Operational Limits. The speed-altitude envelope of the configuration is shown in Figure 40. The maximum dynamic pressure is 600 psf and which limits the maximum speed on the deck to be slightly over Mach 0.6 or less than 400 knots. However, the maximum speed limit at altitude is Mach 1.5 and the configuration is capable of operating up to 60,000 ft. The load factor limits are typical of bombers. Because there are no maneuvering requirements, the maximum load factor is 3 and the minimum load factor is -1. The load factor limits can be seen in Figure 41.



SKETCH NOT TO SCALE

Figure 39
Proposed Strategic Bomber Configuration

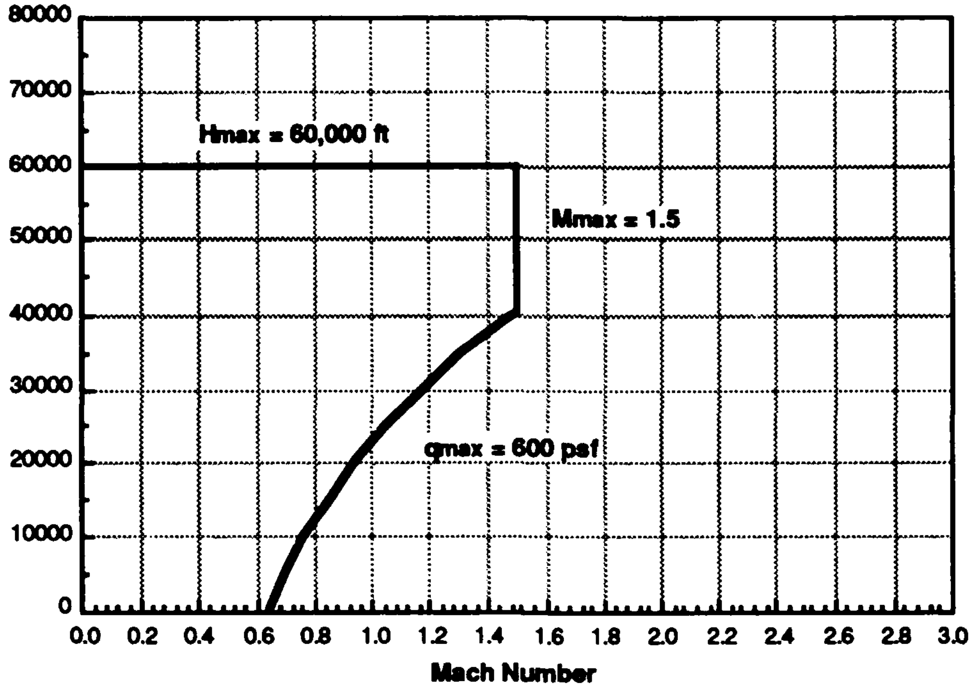


Figure 40
Speed - Altitude Limit Diagram for Strategic Bomber

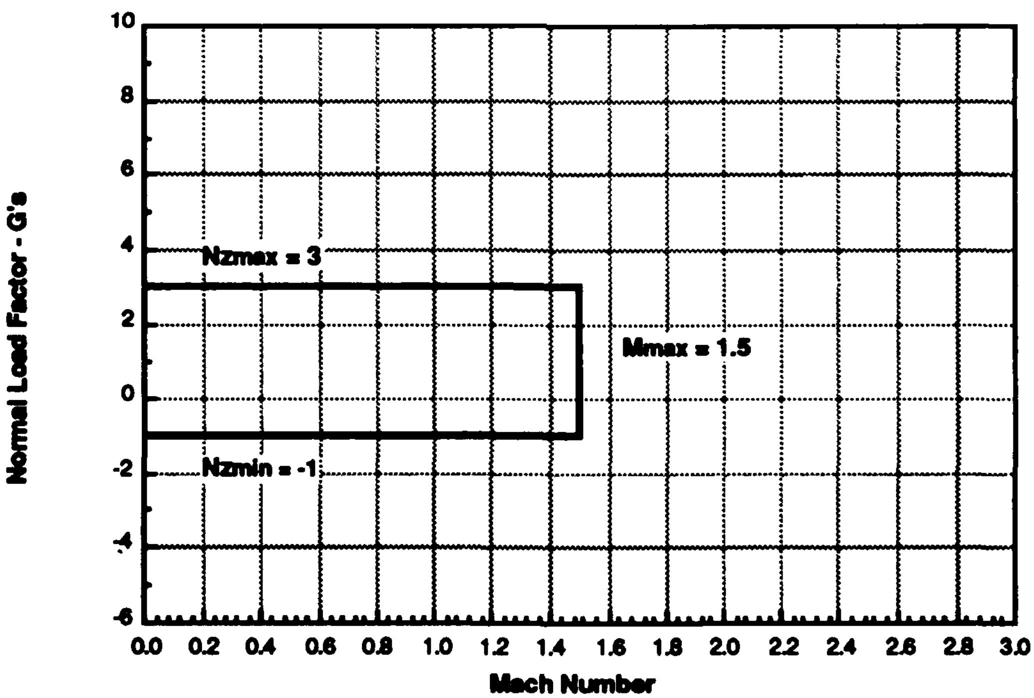


Figure 41
Strategic Bomber Limit Load Diagram

2.2.4.6.3 Mission Profile Characteristics. A mission profile for this configuration is shown in Figure 42. After takeoff, the aircraft climbs up to the cruise altitude and Mach number for best range. The optimum cruise speed and altitude for this configuration is approximately Mach 0.8 and 30,000 to 40,000 ft. The vehicle cruises for a long period of time to meet the 5,000 nm mission radius. At about 1,000 nautical miles (nm) from the target, the aircraft accelerates to supersonic speeds and locates the target. After weapons launch, the aircraft egresses from the target area also at supersonic speeds. After a safe distance away, the vehicle slows down to best cruise speed and altitude. Upon return to the base, a 20 minute loiter is included for reserves.

Due to the very long ranges that are required to accomplish the mission, almost 80% of the mission time is spent at cruise conditions. Although the concept penetrates a 1,000 nm radius at supersonic speeds, the representative flight time is only 12%. The remaining flight time is split between the climb and acceleration legs.

2.2.4.6.4 Operational Characteristics. The low altitude operations are limited to takeoff and landing. The aircraft can takeoff at maximum weight, lifting off at approximately 175 knots and passing over the obstacle at 190 knots. The landing weight was assumed to be with 80% of the fuel out. For this weight, the obstacle speed is approximately 150 knots and the touchdown speed is 135 knots.

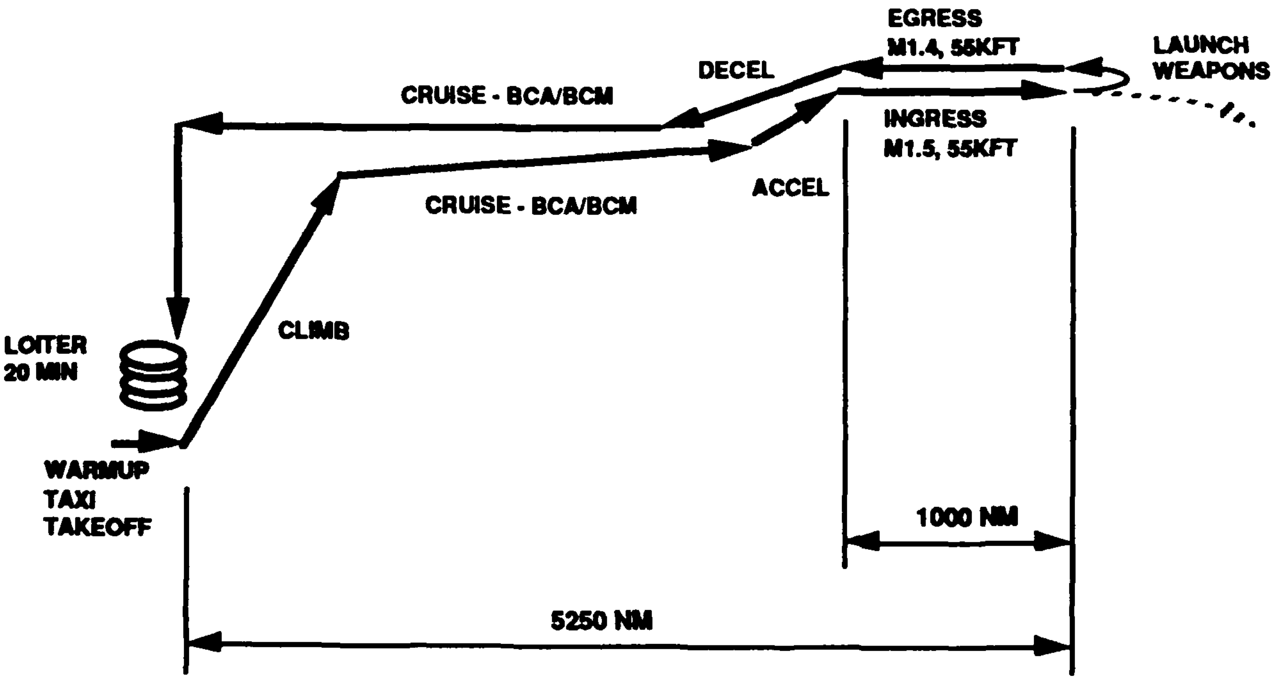


Figure 42
Strategic Bomber Mission Profile

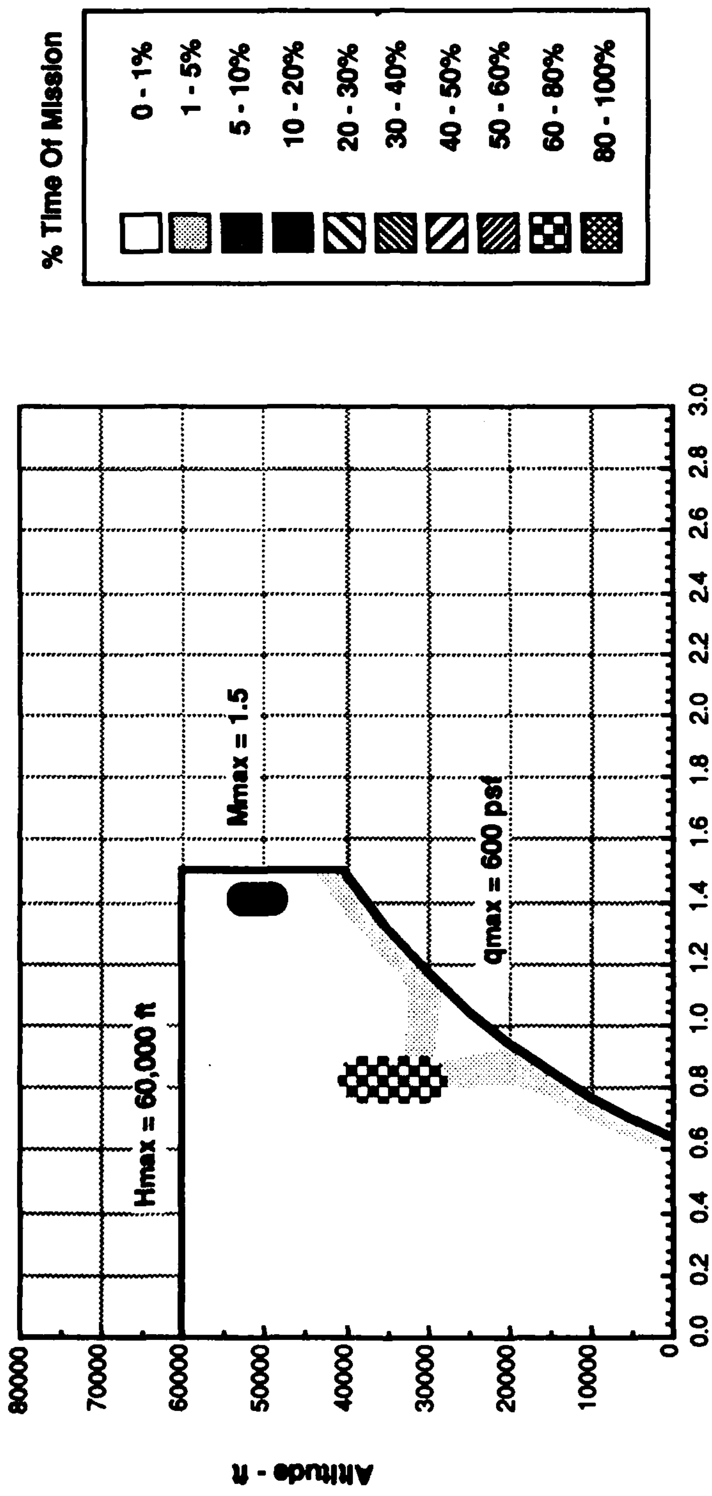


Figure 43
Strategic Bomber Mission Breakdown

2.2.4.7 Special Operations

2.2.4.7.1 Configuration Dependent Parameters. The Special Operations Forces (SOF) configuration requirements are unique due to the VSTOL requirement. At heavy weights, the configuration is capable of performing short takeoffs with approximately 1,500 ft required for ground roll. At the objective area, the vehicle is lighter due to the fuel burnt and the vehicle is capable of hovering or landing vertically. The configuration is shown in Figure 44. Four doors on the top and on the bottom of the wing open to allow the four tip driven lift fans to produce vertical thrust. A small lift fan is also opened near the tail for trimming. These lift fans are driven by separate engines and cross ducted for engine out cases. During cruise mode, the lift fans are shut off and the doors close. In addition, two of the main engines turn off so that the power requirements are at a better match.

Like the strategic bomber, the SOF configuration is one of the few configurations where maneuver requirements are not a driver. The vehicle is aerodynamically stable with goal stability levels near 5%. The vehicle is not capable of going past stall and will probably not be able to roll inverted. Minimum roll rates are defined in MIL-F-8785 to be 32 deg/s.

2.2.4.7.2 Aircraft Operational Limits. The SOF requirements is for a pure subsonic aircraft. The speed-altitude envelope of the configuration is shown in Figure 45. The maximum dynamic pressure is 800 psf and sets the maximum speed on the deck to be slightly over Mach 0.7. At altitude, the speed is limited by the drag divergence Mach number of 0.8. The maximum expected altitude is 40,000 ft. However, most of the mission profiles are expected to be flown at low altitude in the high threat area. The load factor limits are the same as the strategic bomber and other similar cargo aircraft. The maximum load factor for the aircraft is 3 and the minimum load factor is -1 as shown in Figure 46.

2.2.4.7.3 Mission Profile Characteristics. A mission profile for this configuration is shown in Figure 47. Because of the high threat scenarios that are exposed to the SOF aircraft, the mission is entirely at low altitude. After takeoff, the aircraft accelerates up to the cruise speed slightly over Mach 0.5. At the objective area, the vehicle hovers for 5 minutes as the personnel are either loaded on or off the aircraft. The requirement for hover is that it be performed at 4,000 ft on a hot day. The cruise back is identical to the ingress. Upon return to the base, a 20 minute loiter is included for reserves.

The mission flight time breakdown is shown in Figure 48. As can be seen, only the lower portion of the flight envelope is utilized. Approximately 90% of the mission is at the low altitude cruise condition. The remaining 10% is split between the acceleration legs and the hover leg. For ferry missions, more of the flight envelope is utilized. However, still more than 90% of the mission flight time is at the cruise condition. The ferry mission cruise point is projected to be at 25,000 ft near Mach 0.7.

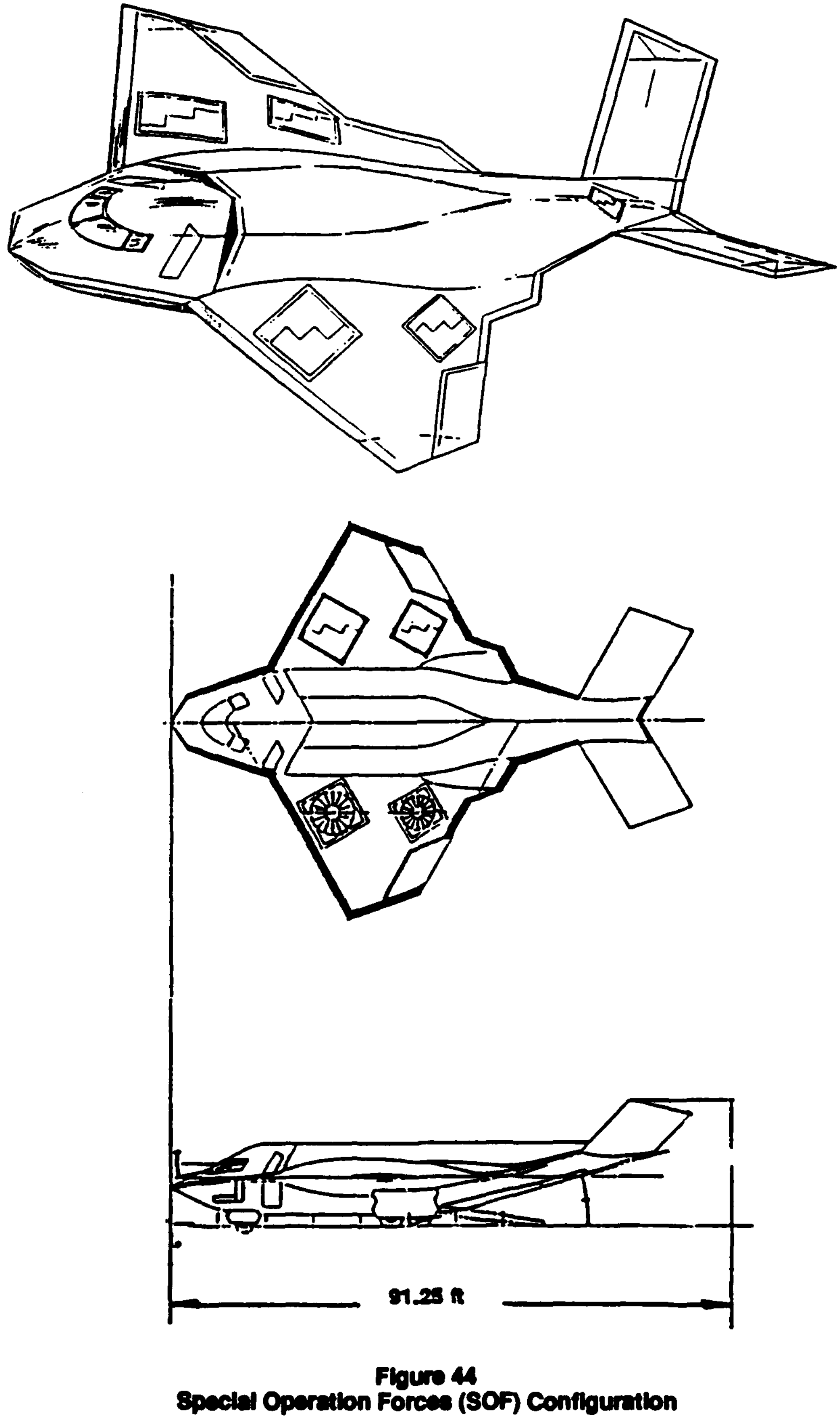


Figure 44
Special Operation Forces (SOF) Configuration

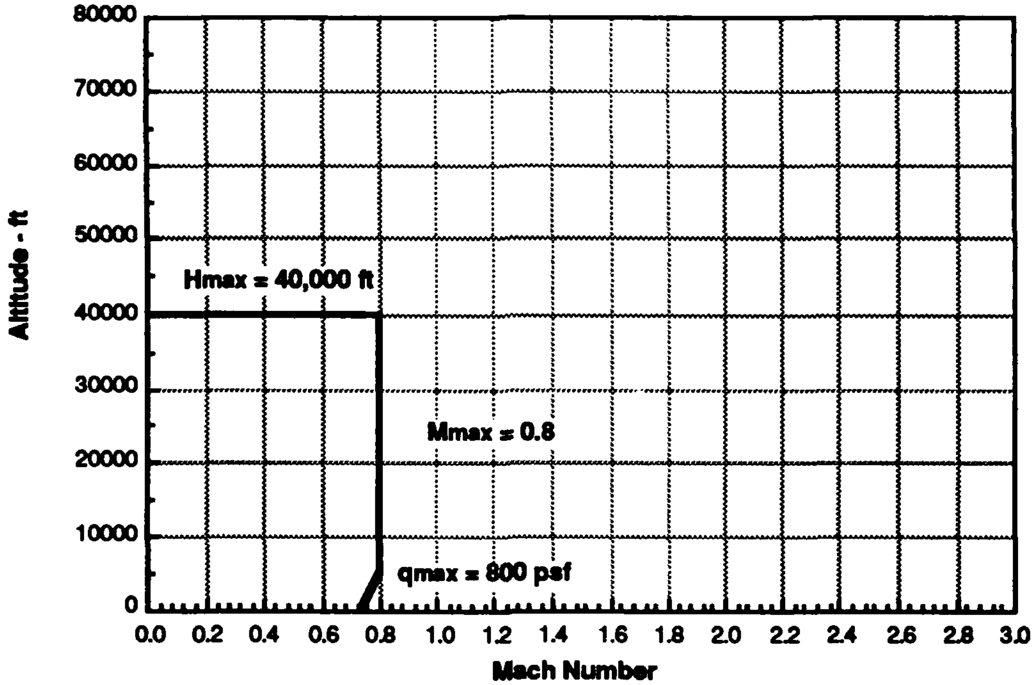


Figure 45
SOF Speed - Altitude Limit Diagram

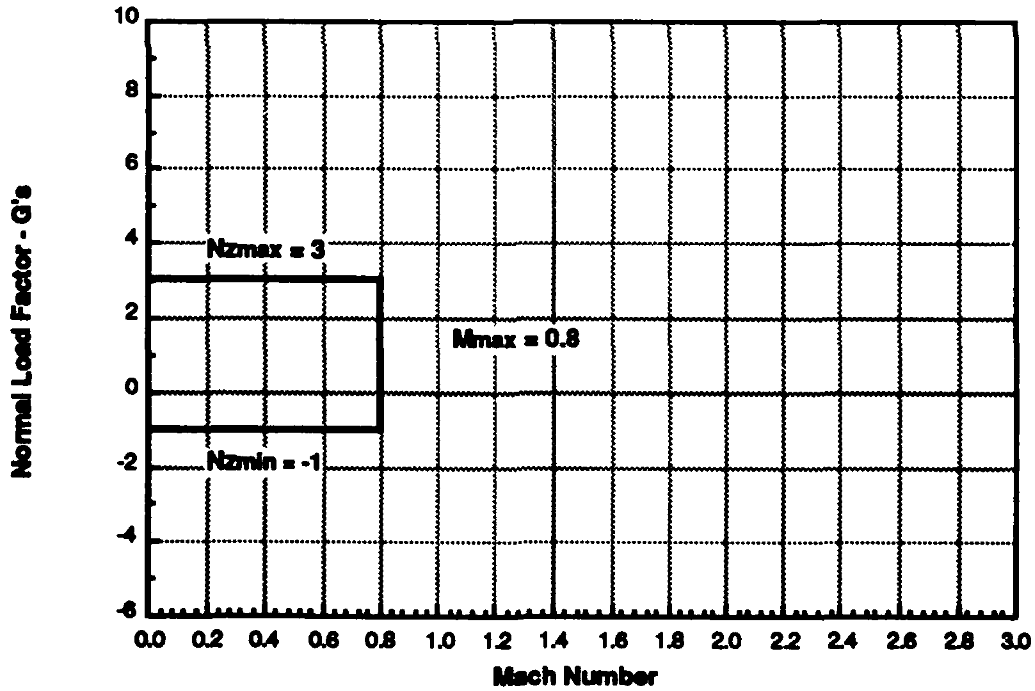


Figure 46
SOF Limit Load Diagram

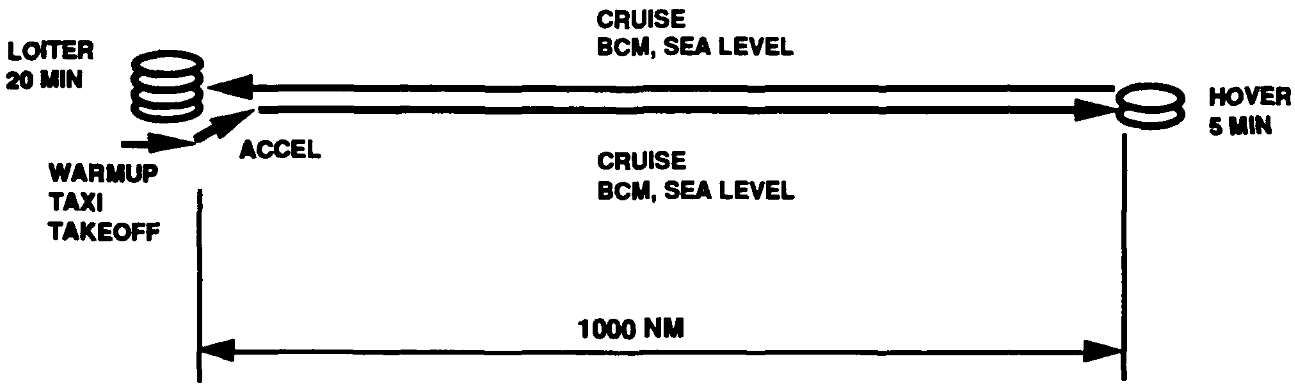


Figure 47
SOF Design Mission Profile

2.2.4.7.4 Operational Characteristics. The vehicle relies heavily on terrain following to increase survivability. The speed during the TF/TA operations is expected to be 350 knots and at an altitude of 200 ft AGL. One possible problem with the VTOL system is the transition from horizontal flight to vertical flight. This is a region where there may exist a great deal of instability. However, this vehicle is better than the CV-22 for crew escape during this portion since this configuration has no overhead rotors to consider. For normal takeoff and landing cases, the speeds are relatively low. Takeoff at maximum weight results in a liftoff speed of 104 knots and an obstacle speed of 114 knots. For landing with 80% fuel out, the approach speed is 93 knots and the touchdown speed is 85 knots.

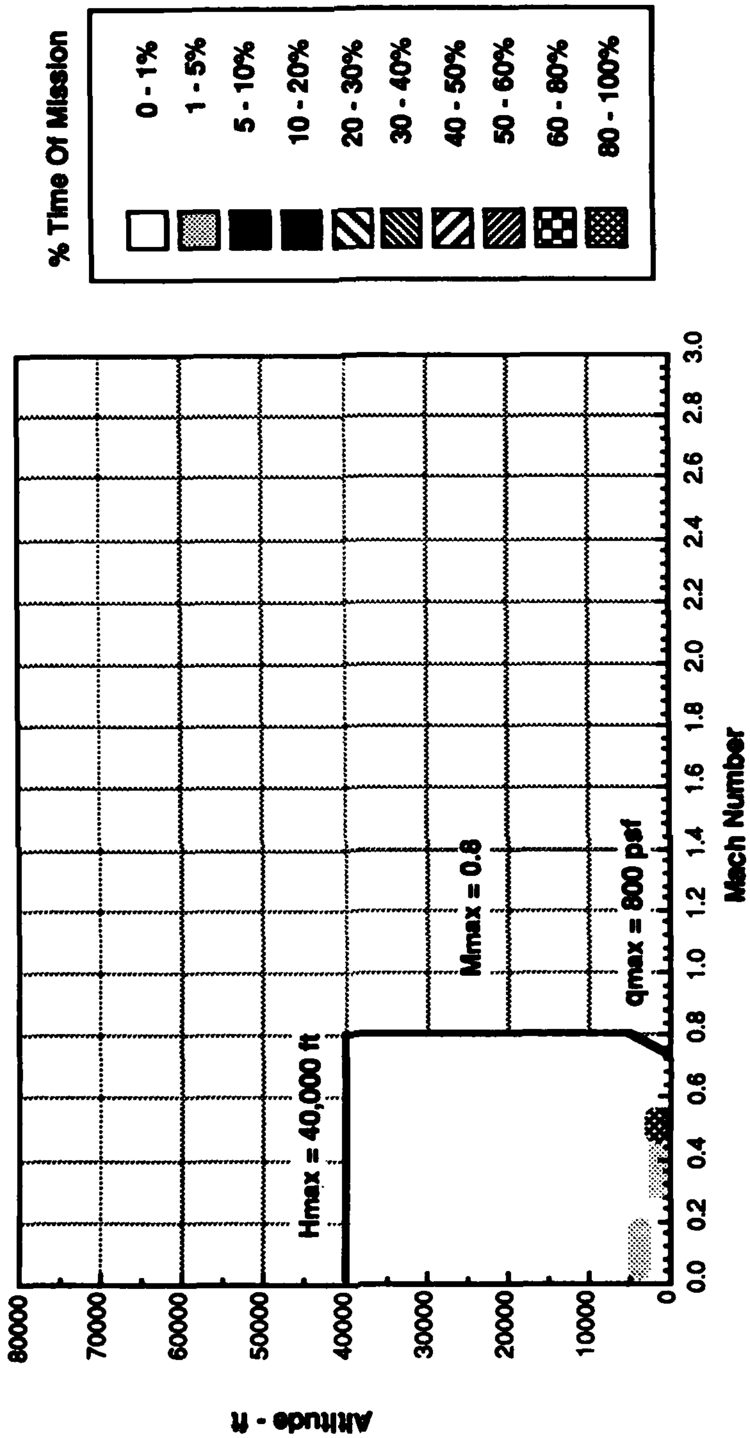


Figure 48
SOF Design Mission Breakdown

2.2.4.8 Hypersonic Interceptor

2.2.4.8.1 Configuration Dependent Parameters. With the recent advances in materials and propulsion, the hypersonic speed region is becoming more attractive to aircraft designers. This speed range covers Mach numbers from 5 up to 26 which is near orbital speeds. One such application at the low end of the hypersonic speed range is a deck launched interceptor (DLI). The main advantage to this system is that the hypersonic speeds reduce the time between target acquisition and intercept.

The configuration developed for the DLI is capable of Mach numbers over 4.5 with non-cryogenic fuels as shown in Figure 49. The vehicle uses twin turbo-fan ramjets to allow operations over Mach 4.5. The variable sweep wing allows efficient operations during both carrier operations and hypersonic flight. The configuration is aerodynamically stable with a goal stability set to slightly less than 5%. The aircraft is limited in pitch by conventional stall during low speeds and possibly by the engine inlet during hypersonic speeds. During low speeds, the vehicle is able to perform 360 degree rolls at rates which are not yet defined. If the vehicle is to meet military specifications at low speeds, the the roll rate is defined in MIL-F-8785 to be 128 deg/s. At hypersonic speeds, the vehicle will probably not be able to perform 360 degree rolls. The forebody is rather conventional but the flow field is not known around the canopy. However, the temperatures during hypersonic cruise are expected to be as high as 800 °F at the canopy.

2.2.4.8.2 Aircraft Operational Limits. *The speed-altitude envelope of the configuration* is shown in Figure 50. The maximum dynamic pressure is 2000 psf and which allows some supersonic capability at sea level but is mostly for the capability of hypersonic speeds at altitudes near 60,000 ft. The maximum Mach number is at 4.6 with a maximum altitude set at 100,000 ft. The loading limits are shown in Figure 51 and are typical of interceptors. A maximum load limit of 5 and a minimum load limit of -3 is expected with the wings swept back. When the wings are swept forward, the maximum load factor is set to 3.

2.2.4.8.3 Mission Profile Characteristics. A typical intercept mission is shown in Figure 52. After launching from the carrier, the vehicle does a maximum power climb up to Mach 4.5 and best cruise altitude near 80,000 ft. After over 500 nm and only 16 minutes into the mission, the aircraft engages the target within a 2 minute time frame. At this point, the vehicle descends for maximum range to best cruise speed and altitude near Mach 0.6 and 25,000 ft. After cruise back, the aircraft loiters for 10 minutes before arresting on the carrier.

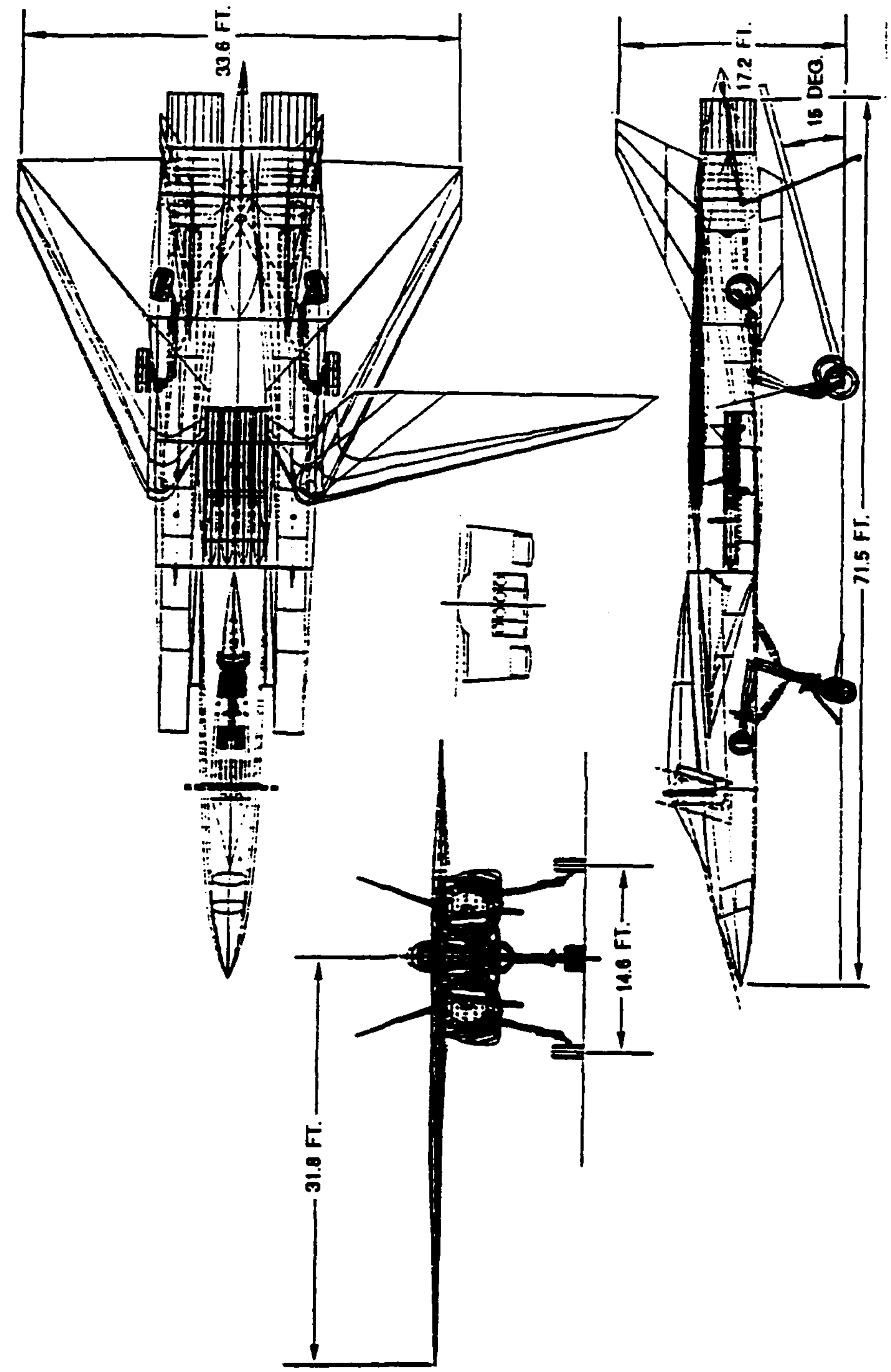


Figure 49
Hypersonic Deck Launched Interceptor Configuration

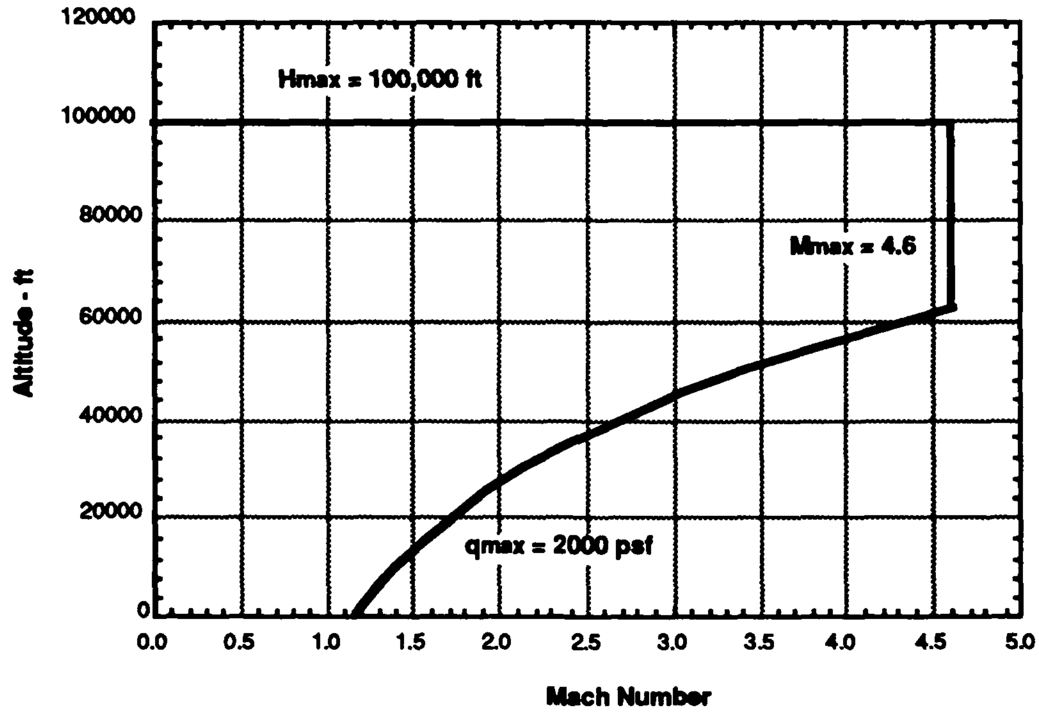


Figure 50
Speed - Altitude Limit Diagram for Hypersonic Interceptor

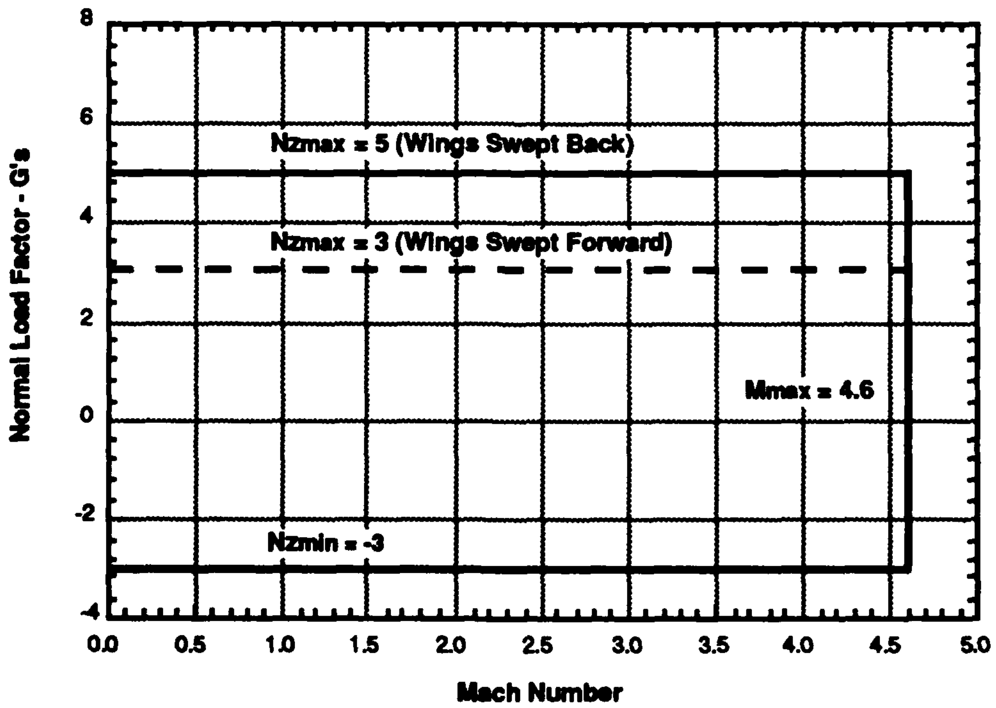


Figure 51
Hypersonic Interceptor Limit Load Diagram

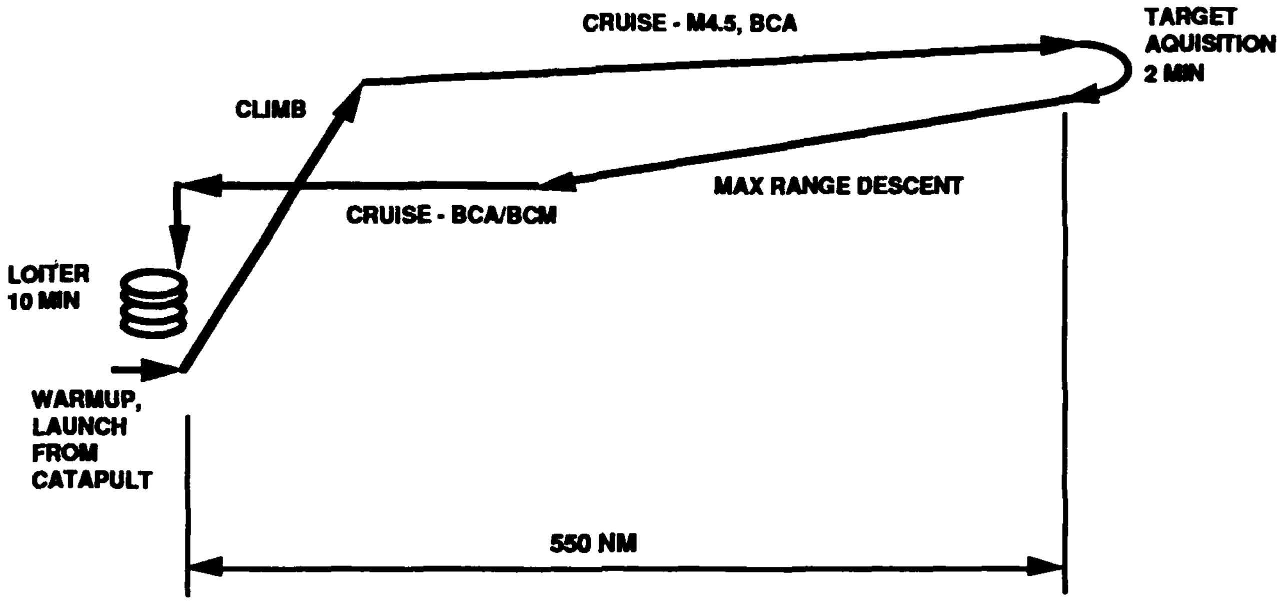


Figure 52
Hypersonic Intercept Mission Profile

The time spent accelerating up to hypersonic speed is short representing 9% of the total mission time. The hypersonic dash out to the objective area represents an additional 12% of the mission time. This sums to a total time out to the target area to be slightly over 20% of the mission time. The descent is performed at maximum lift-to-drag ratio to maximize range. Due to the large differences in energy levels between the hypersonic dash and the subsonic cruise, the descent takes approximately 20% of the mission time and covers nearly 60% of the return mission radius. The remaining 40% of the return mission is at subsonic speeds and takes up slightly more than 45% of the mission time. The remaining time is spent at loiter conditions as shown in Figure 53.

2.2.4.8.4 **Operational Characteristics.** Besides takeoff and landing, the concept has no low altitude capability. All low altitude operations are performed with the wings swept forward. During takeoffs on land, the liftoff velocity is expected to be near 140 knots and then pass over the obstacle at 154 knots. For landing on land with 80% of the fuel removed, the obstacle velocity is expected to be near 116 knots and touchdown at 107 knots. For carrier operations, the end speed for a C13-1 catapult is slightly over 130 knots neglecting wind over deck. During carrier landings using a MK7-MOD3 arresting engine, the maximum approach velocity is slightly under 140 knots.

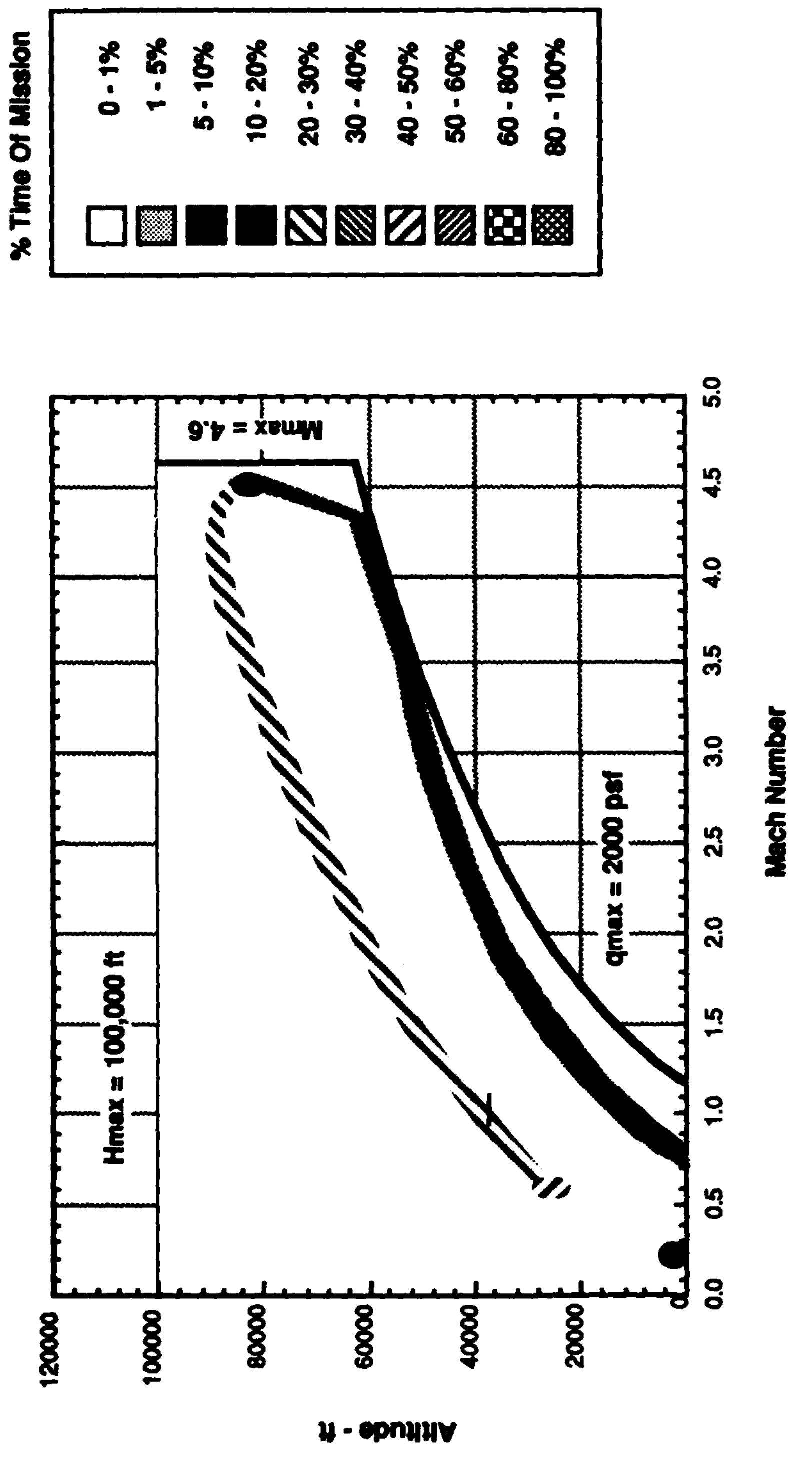


Figure 53
Hypersonic Interceptor Mission Breakdown

2.2.4.9 Hypersonic Reconnaissance (SSTO)

2.2.4.9.1 Configuration Dependent Parameters. The hypersonic reconnaissance vehicle is on the opposite end of the hypersonic speed range with Mach numbers approaching 26 before inserting into orbital conditions. This single stage to orbit (SSTO) configuration is shown in Figure 54 and is similar to the National Aerospace Plane (NASP). Unlike the Space Shuttle, the vehicle takeoffs horizontally and accelerates to near orbital Mach numbers without any expendable propulsion system where the vehicle then inserts into a circular orbit approximately 100 nm in altitude. The propulsion requirements are extreme and no single system can meet the entire mission. During low speed operations, the vehicle may use a conventional turbo-jet engine or a more unconventional liquid air cycle engine (LACE). The LACE system is what the Japanese are proposing for a SSTO. During the middle Mach numbers from 3 to approximately 6, ramjets could be used for the propulsion system. For true hypersonic speeds above Mach 6, scramjets will be used to accelerate the vehicle up to near orbital Mach numbers. To insert the vehicle into a circular orbit and to de-orbit, the configuration must have a rocket to provide the required delta velocity. In addition, several attitude control rockets must be included for maneuvering the vehicle during space operations.

The vehicle is to be aerodynamically stable but the goal stability level is not known by the author. The aircraft is limited in pitch by conventional stall during low speeds and by the engine inlet during hypersonic speeds. During hypersonic flight, the entire forebody is used as a compression surface for the inlet and the entire aftbody is used as nozzle exhaust. The vehicle does not fit within any of the aircraft types specified in MIL-F-8785 and so the roll rates and limits are not defined. It is expected that the vehicle will be able to perform a maximum roll angle of 100 degrees at a rate near 75 deg/s. The flow field around the canopy is not known at this time and may be favorable during low speeds. During hypersonic operations, the high temperatures around the canopy is the most critical issue.

2.2.4.9.2 Aircraft Operational Limits. The speed-altitude envelope of the configuration is the largest of all of the aircraft types as shown in Figure 55. The maximum dynamic pressure is 2000 psf which is set by the scramjet limitations. As the dynamic pressure decreases, the altitude that the vehicle operates at during hypersonic flight will be too high due to the insufficient air mass flow to the scramjets. It should be noted that at the very high Mach numbers at maximum dynamic pressure, temperature limits may be imposed and will in effect decrease the maximum dynamic pressure. Because these temperature limits are both configuration and attitude dependent, they are not shown on the chart. Typical maximum temperatures during ascent are on the order of 1500 to 2000°F. The maximum speed is that velocity which is required to sustain a 100 nm high circular orbit which corresponds roughly to Mach 26. The maximum and minimum load factors are set to +3 and -1 respectively as shown in Figure 56.

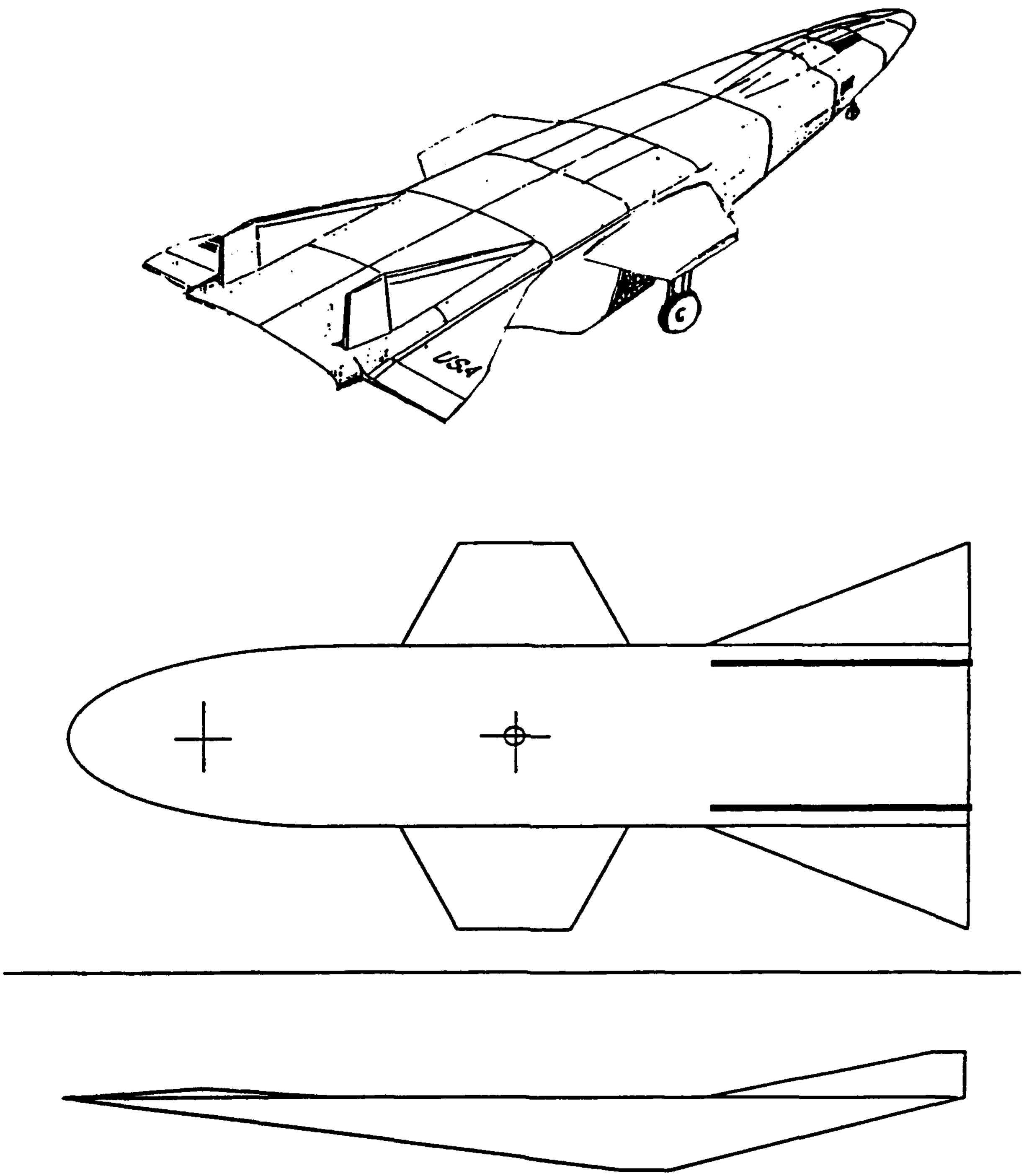


Figure 54
Hypersonic Reconnaissance Configuration (SSTO)

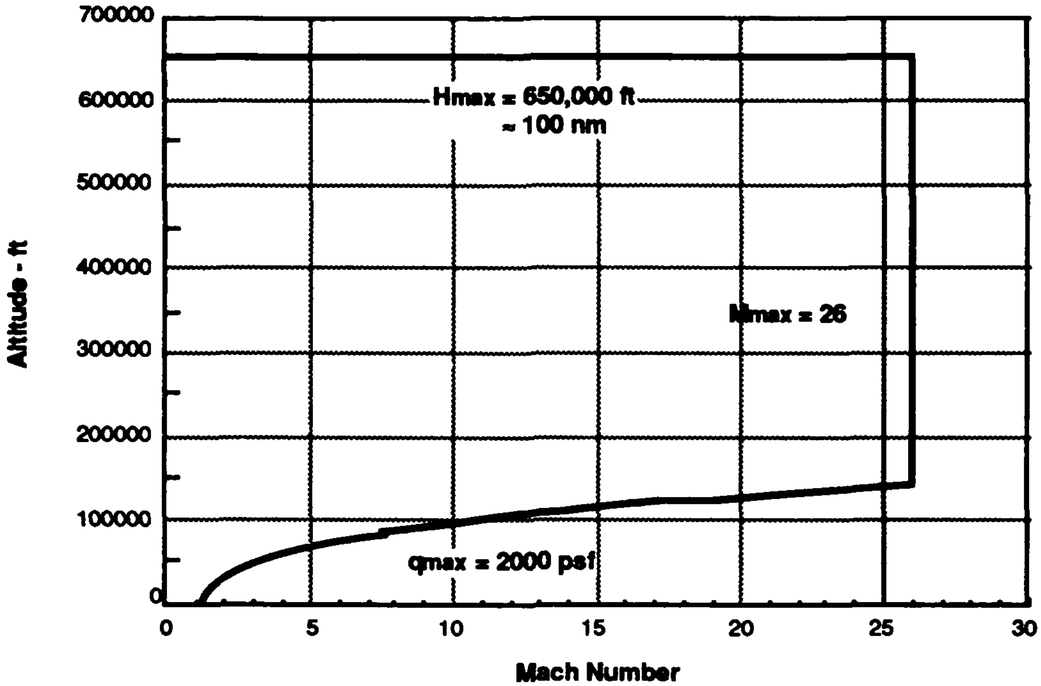


Figure 55
Flight Envelope Limits for the SSTO

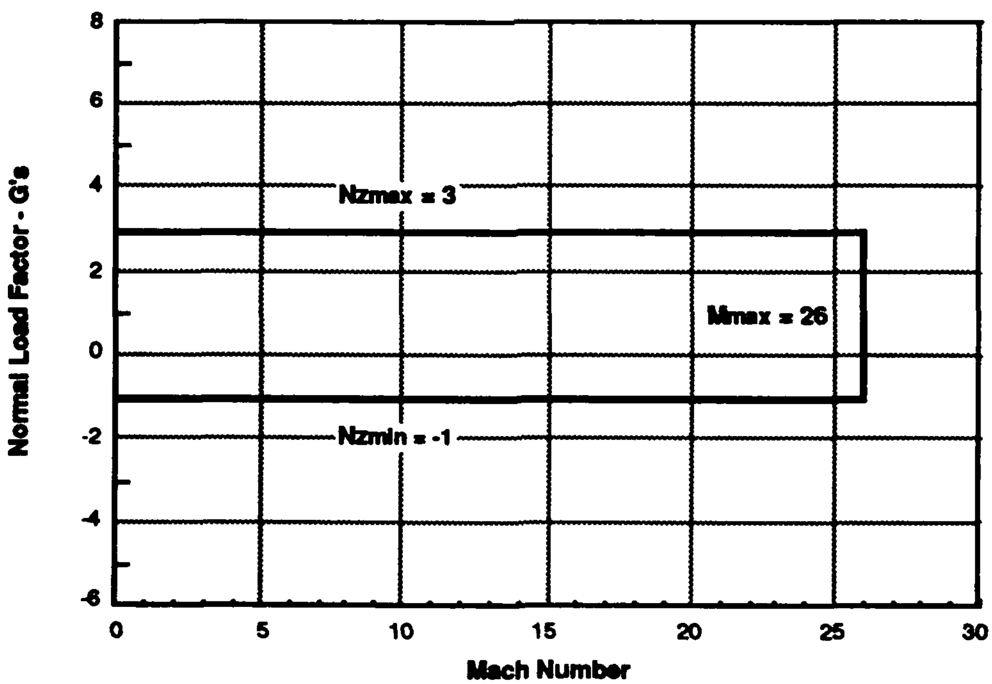


Figure 56
Load Factor Limits for the SSTO

2.2.4.9.3 Mission Profile Characteristics. The hypersonic reconnaissance mission is shown in Figure 57. After takeoff the vehicle climbs up through the subsonic, supersonic and into the hypersonic speed region. At some point during the hypersonic climb, the vehicle shuts off the scramjets and performs a pull-up maneuver that minimizes the velocity loss. Once the vehicle reaches the desired orbit altitude, the vehicle performs a rocket burn to stabilize a circular orbit. Four orbits are assumed for this mission and consume approximately 90 minutes each at this orbit altitude. The maximum number of orbits is a function of the size of the life support systems that are carried on board the vehicle. After completing all of the orbits, the vehicle performs another rocket burn which slows the vehicle and causes the vehicle to de-orbit.

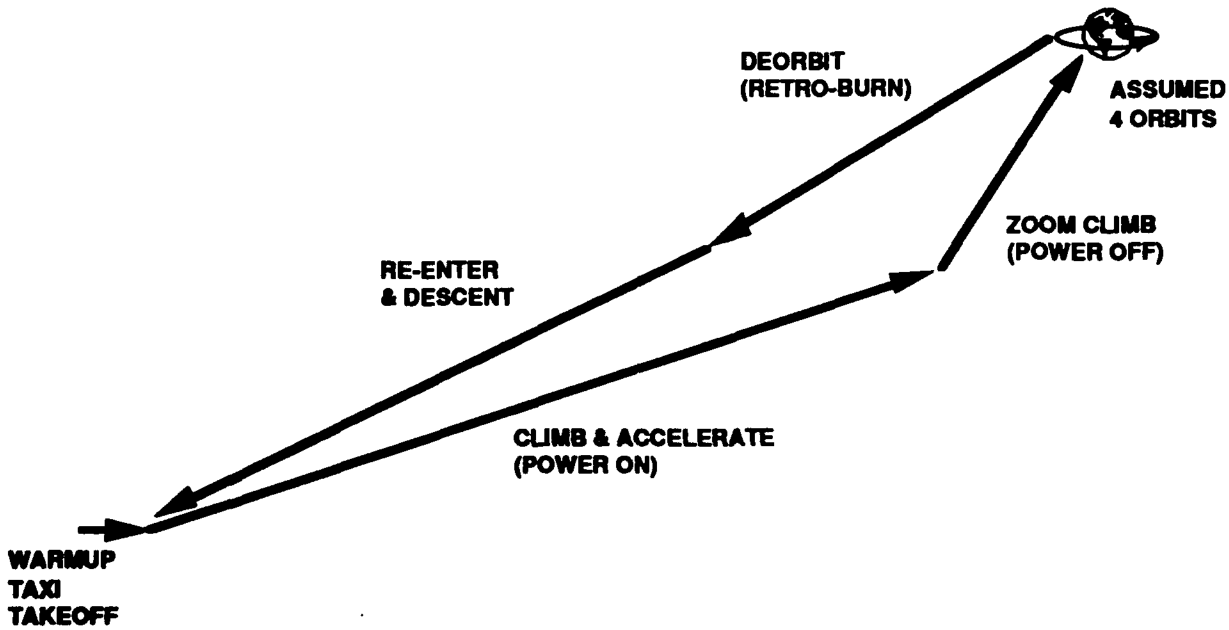


Figure 57
Hypersonic Reconnaissance Mission Profile

The majority of the mission time is spent during the orbit phase where the assumed 4 orbital periods consumed almost 76% of the total mission time. The power on acceleration represents almost 3% of the total mission time and an additional 3% of the mission time is spent performing the power off zoom climb. The Mach number at the beginning of the zoom climb is estimated by the author to be 17 but may not represent a true condition. After the orbit legs, the vehicle reenters the atmosphere and descends representing approximately 18% of the total mission time. As the number of orbits increase, the climb and descent legs will have lower mission time percentages. If the orbital time is removed from the mission time, the power on climb leg and the power off zoom climb would each represent 12% of the mission time. The remaining 76% of the mission time would be for reentry and descent.

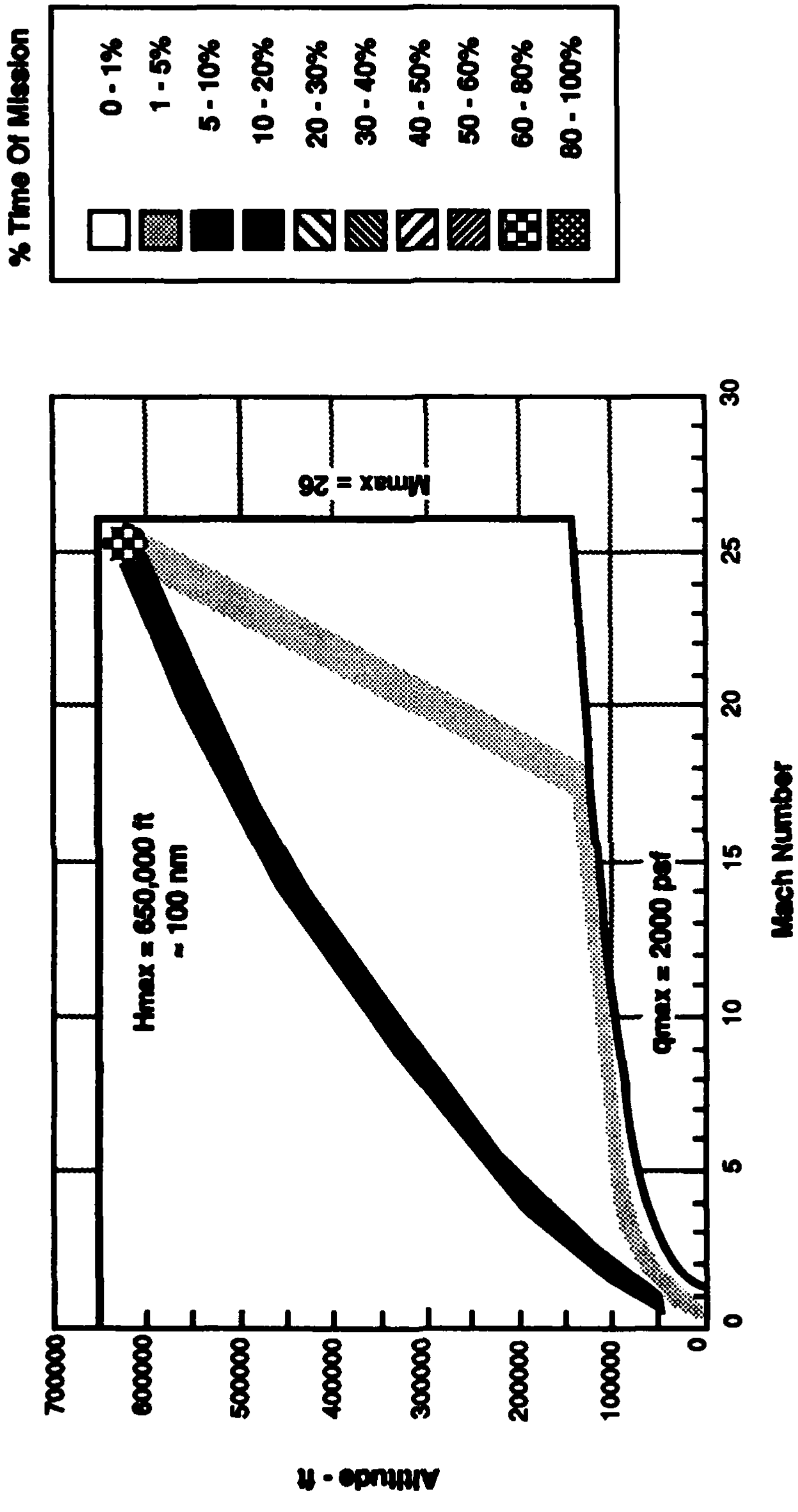


Figure 58
Mission Breakdown for the Hypersonic Reconnaissance Profile

2.2.4.9.4 Operational Characteristics. The low altitude operations are limited to takeoff and landing. During the high speed operations, there is little need for wing area. However, the wing area is critical for takeoff and landing and so the size must be compromised to meet both mission requirements. Due to the small wings of the aircraft and the poor lift coefficient of the highly swept configuration, the takeoff and landing speeds are expected to be greater than most of the configurations. It is expected that the aircraft will be capable of lifting off at 235 knots and pass over the obstacle at 255 knots. During the landing, the vehicle should be able to pass over the obstacle at 190 knots and touchdown at 175 knots.

2.2.4.10 System Comparisons. When comparing some of the operational parameters for the escape / ejection requirements, it soon becomes apparent that each of the aircraft types have a wide spectrum of requirements. Some of these aircraft types may be grouped together based on a single common operational parameter. However, none of these aircraft types can be grouped together based on all of the operational parameters.

A comparison of the flight limit envelops for each of the aircraft types is shown in Figure 59. Both of the hypersonic aircraft were eliminated from this chart because the speed and altitude ranges are significantly different from the other aircraft types. The trainer has the smallest flight envelope, allowing only slow speeds at relatively low dynamic pressures to increase safety. The special operations aircraft and the close support aircraft have the next two smallest flight envelopes as they are purely subsonic designs. Of the supersonic aircraft, the bomber has the smallest envelope due to the low dynamic pressure. This aircraft has little operational capabilities at low level. The next largest flight envelope is the attack aircraft followed by the air superiority aircraft. As explained in section 4.1, the maximum speed of this configuration is postulated to be expanded to be near Mach 2.2 and would thus be the highest speed aircraft apart from the hypersonic vehicles. The fighter configuration has the largest flight envelope due to the many operational missions that are proposed for this aircraft. This is the only configuration that has true supersonic capability at sea level apart from the hypersonic aircraft.

A comparison of the load factor limits is shown in Figure 60. As can be seen, the variation in load factor is not necessarily a factor of speed. The trainer and the close air support aircraft have a much wider range in load factor than the special operations aircraft. This is because the SOF aircraft is to be used mainly for transport and does not have significant maneuver requirements. This is also seen in the supersonic speed range where the bomber is limited to loads of +3 and -1. This is contrary to the +9 and -4 load limits of most of the other aircraft. Again note that the hypersonic aircraft were removed from this chart due to the speed differences. In addition, the proposed speed addition is shown in dashed lines for the air superiority aircraft.

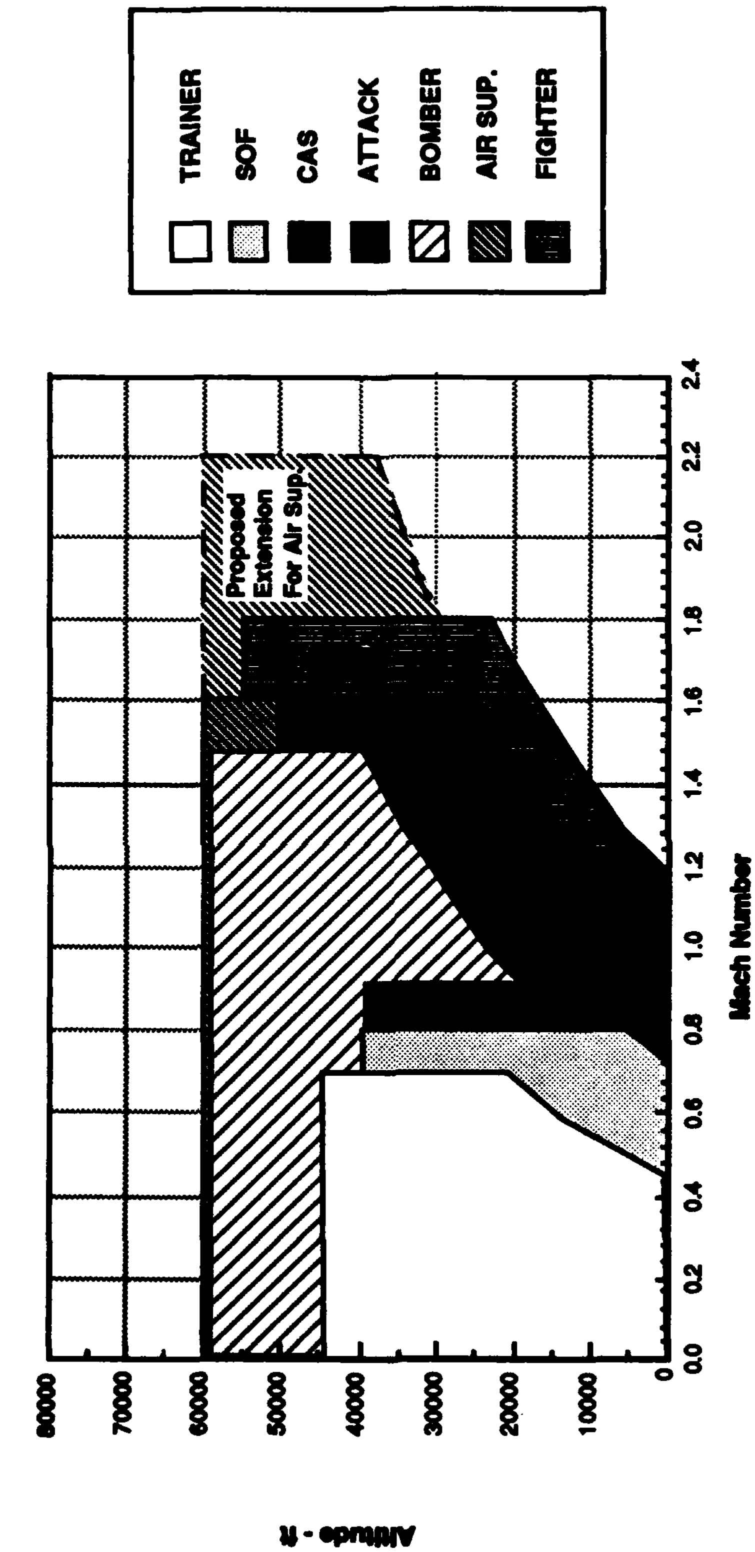


Figure 59
Flight Envelope Comparison

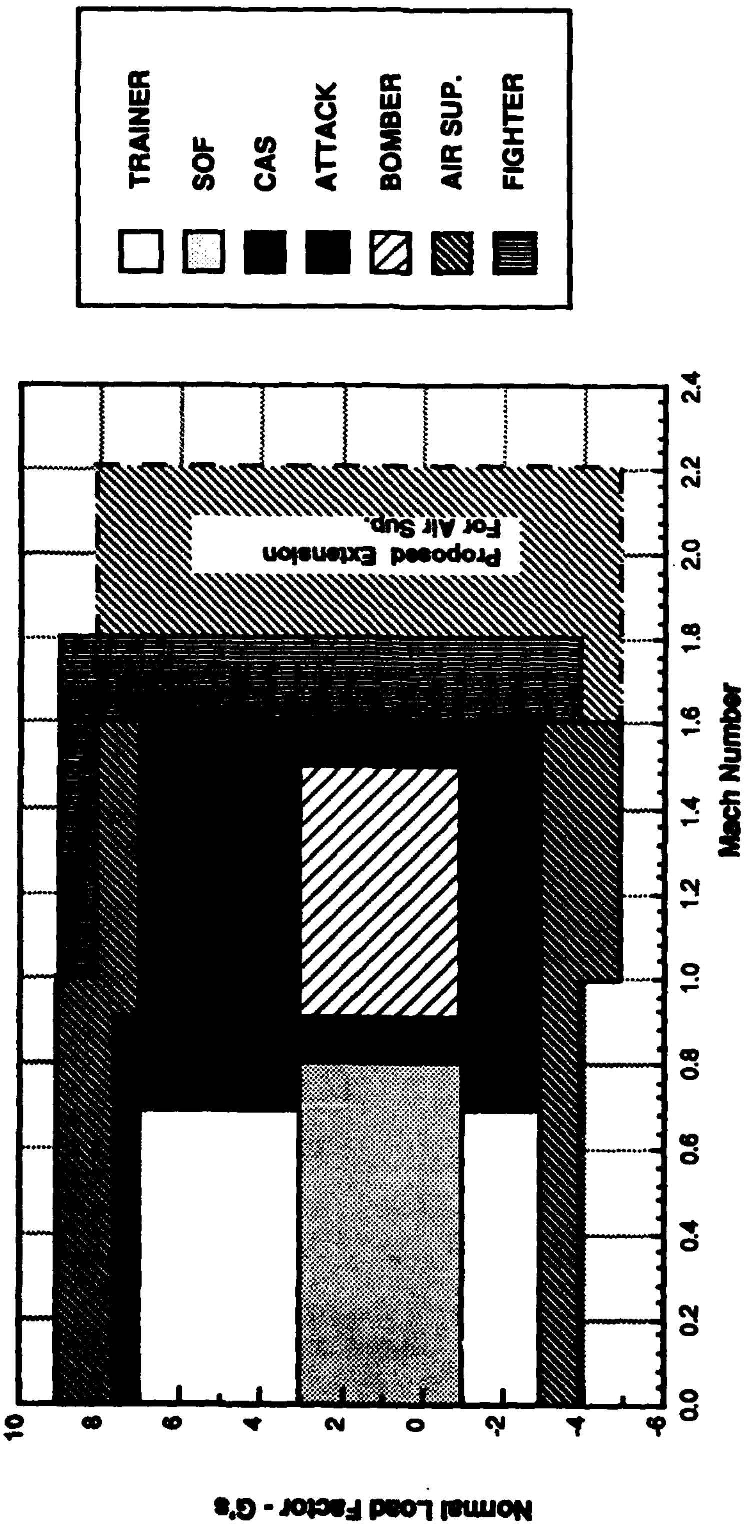


Figure 60
Load Factor Envelope Comparison

The speed differences during different portions of the mission are shown in the next three figures. The differences in takeoff velocity is shown for the various aircraft types in Figure 61 for both lift off and obstacle conditions. The aircraft with the slowest takeoff speeds include the CAS, SOF and trainer systems. This is due to the STOL requirements for the CAS and SOF aircraft and the safety aspect for the trainer system. Most of the tactical aircraft can takeoff within 150 knots and are mostly CTOL designs. The attack and the bomber systems can takeoff with 200 knots and the hypersonic reconnaissance vehicle has the highest takeoff velocity near 250 knots.

The landing speed comparison is shown in Figure 62 with similar results to the takeoff comparison. The trainer aircraft has the lowest landing speeds near 50 knots. Because landing is one of the more difficult operations for a new pilot, the landing speeds are extremely low when compared to the other systems. The vehicles that have some STOL capability (CAS and SOF), can both land within speeds of 100 knots. All other aircraft can land within 150 knots with the exception of the hypersonic reconnaissance vehicle which lands at speeds under 200 knots.

The velocities expected during terrain following / terrain avoidance operations are shown in Figure 63. Note that the air superiority, trainer, bomber and both hypersonic aircraft systems do not use TF/TA in their missions. The SOF aircraft penetrates at the slowest speeds near 350 knots which is near Mach 0.5. The fighter and the CAS aircraft have higher penetration speed near 500 knots which corresponds approximately Mach 0.75. However, it should be noted that the fighter configuration, with the highest dynamic pressure, is capable of penetrating at Mach 1.2 which is almost 800 knots. The attack aircraft has the highest operational penetration speed at 600 knots which is near Mach 0.9.

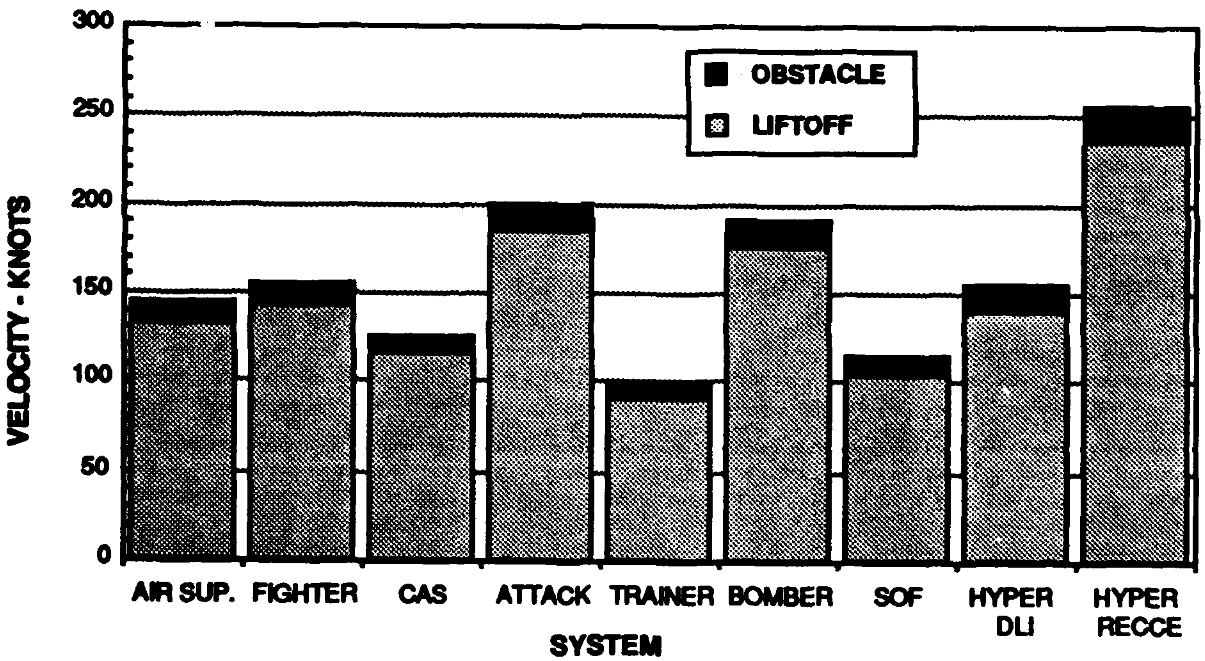


Figure 61
Takeoff Speed Comparison

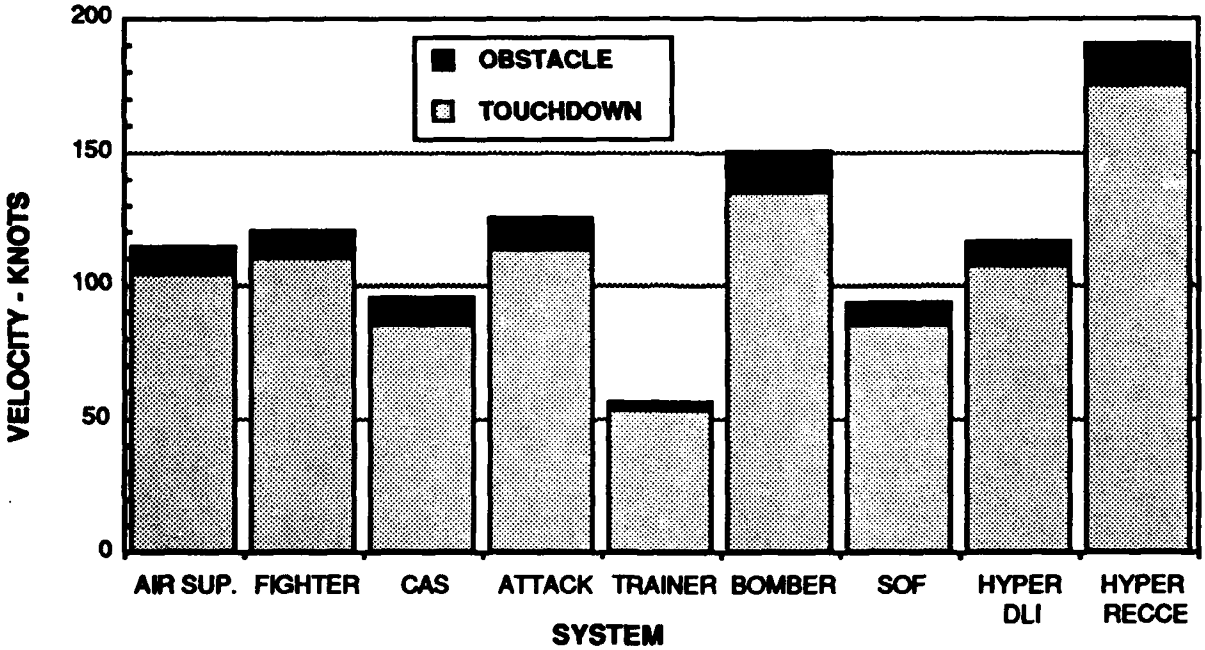


Figure 62
Landing Speed Comparison

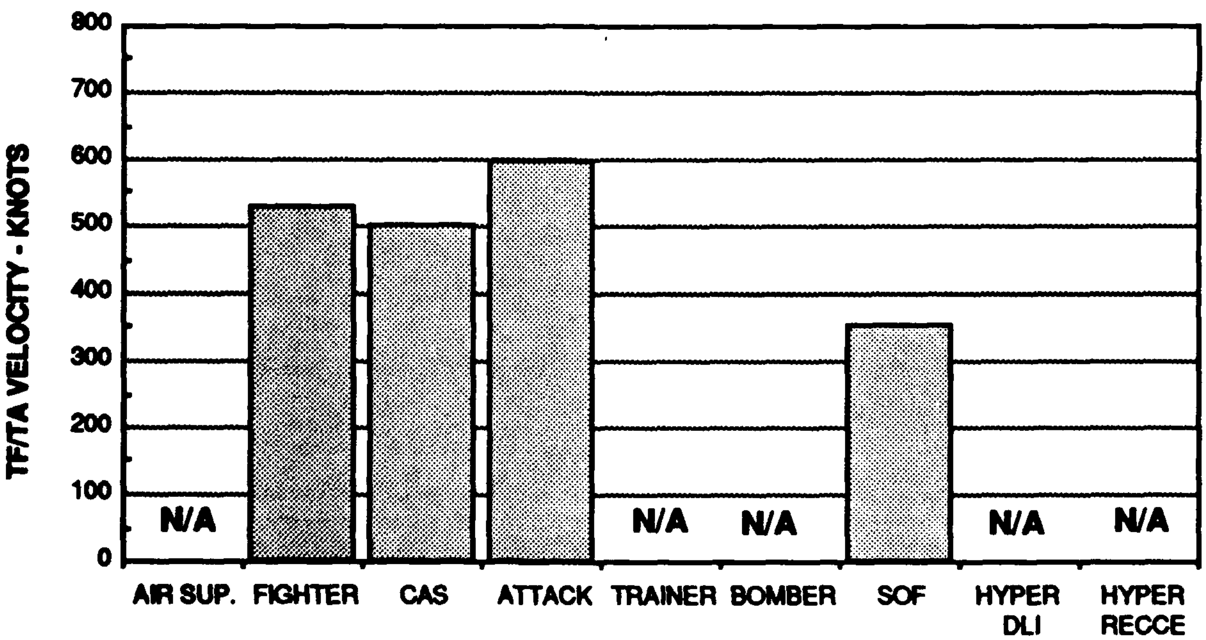


Figure 63
TF/TA Speed Comparison

The attitude limits for the various aircraft types are listed in Table XIX. The pitch attitude limits are in general terms instead of actual numbers. Any configuration that had additional control power over conventional systems were assumed to have some limited amount of post stall capability. This applies to the air superiority, fighter, CAS and attack aircraft. The trainer, SOF, bomber and both hypersonic aircraft are assumed to be limited by conventional stall. For the hypersonic aircraft, an additional limit is imposed at high speeds due to the propulsion system. These propulsion limits are typically on the order of 5 degrees. The roll limits for most of the aircraft are not applicable as they can perform 360 degree rolls. The bomber configuration may or may not be able to perform complete rolls. For background information, the B-1B is capable of 360 degree rolls as opposed to the B-2 which is limited to rolls less than 180 degrees. The SOF aircraft is not able to roll inverted but the actual limit is not known. The hypersonic interceptor is able to roll inverted at low speeds but this capability is expected to be removed during hypersonic flight. The only roll and yaw limits shown are for the hypersonic reconnaissance vehicle which are estimated to be 100 degrees and 3 degrees respectively.

As discussed in Section 2.2.3, the pitch, roll and yaw rates are typically not known during the conceptual design phase. However, minimum allowable roll rates are specified in MIL-F-8785 and are shown in Figure 64 for reference. A rough estimate is included for the hypersonic reconnaissance since this is not included in the specification. For air-to-air combat phases, the minimum roll rate is 128 deg/s. This applies to the air superiority and fighter aircraft as well as the hypersonic DLI during low speed operations. During hypersonic operations, the roll rate is not known but is assumed the same as the hypersonic reconnaissance vehicle at 75 deg/s. For ground attack operations, the minimum roll rate is specified to be 69 deg/s and applies to the CAS and attack aircraft. The minimum roll rate for the trainer and the SOF aircraft are specified to be 46 deg/s and 32 deg/s respectively. The lowest minimum roll rate is for the bomber aircraft at 20 deg/s.

Table XIX. Attitude Limits for Various Aircraft

System	Pitch	Roll	Yaw
Air Sup.	Post Stall	360 deg	TBD
Fighter	Post Stall	360 deg	TBD
CAS	Post Stall	360 deg	TBD
Attack	Post Stall	360 deg	TBD
Trainer	Conventional	360 deg	TBD
Bomber	Conventional	TBD	TBD
SOF	Conventional	< 180 deg	TBD
Hyper DLI			
Low Speed	Conventional	360 deg	TBD
Hypersonic	Propulsion Limits	< 180 deg	TBD
Hyper Recce			
Low Speed	Conventional	100 deg	3 deg
Hypersonic	Propulsion Limits	100 deg	3 deg

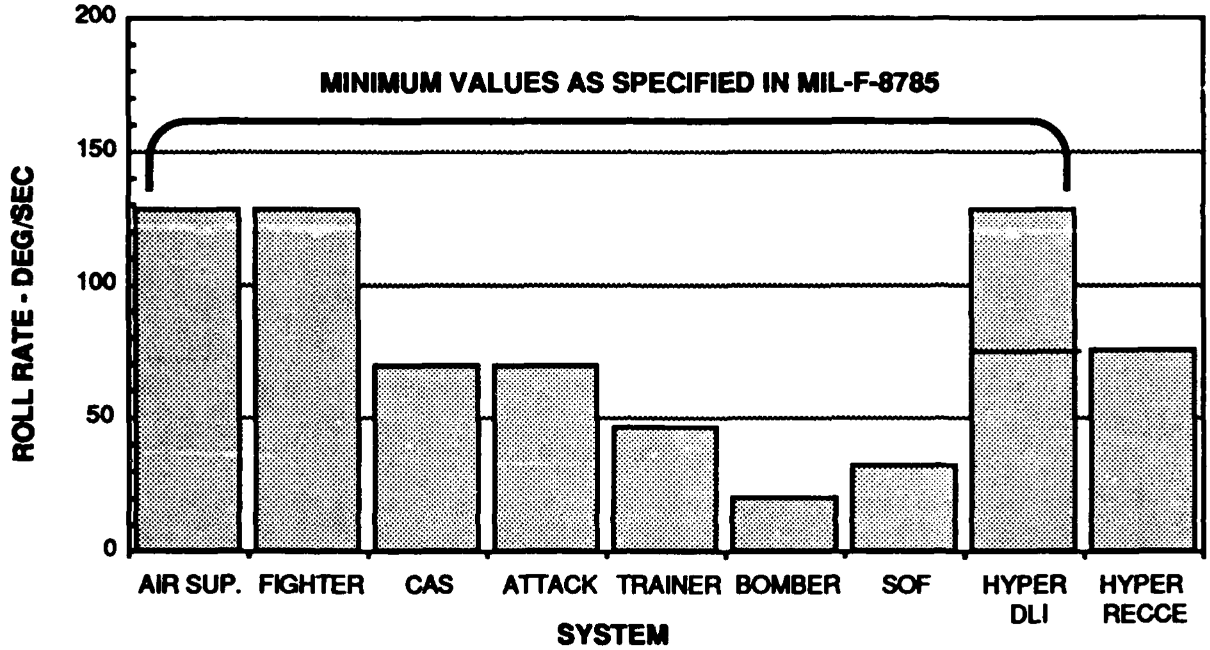


Figure 64
Roll Rate Comparison

The final comparison in this report is the longitudinal stability margins. The longitudinal stability is shown in terms of the static margin which is a percentage of the mean aerodynamic chord, Figure 65. Positive values represent aerodynamically stable aircraft whereas negative values are aerodynamically unstable. A static margin of zero represents a case of neutral stability. The vehicles that use relaxed aerodynamic stability for increased maneuverability are the air superiority and the fighter aircraft. Both of these systems have goal stability levels near 5% unstable. The bomber aircraft uses relaxed stability to decrease the trim drag penalty during cruise. For this case, the goal stability level is for 4% unstable. All of the other aircraft are aerodynamically stable to some degree. The trainer and the SOF aircraft are both very stable with static margins near +5%. The CAS and attack aircraft have stability levels between 2.5 and 5% stable. Finally, the hypersonic aircraft are both stable with static margins near 4%.

2.2.5. Conclusions. The operational requirements of future DoD aircraft have been shown to be quite diverse. For some of the operational parameters, the aircraft types can be grouped into similar classes. However, when considering all of the operational parameters as a whole, none of the aircraft types can be grouped together. This can illustrated by comparing the CAS to the SOF aircraft. The flight envelopes of the two configurations are very similar. However, when comparing the load factor limits, the CAS aircraft has a much larger operating envelope. This is true for the other classes of aircraft.

Because of the wide spectrum of requirements, a difficult challenge lies ahead for the ejection / escape system designer. Designing an ejection system that can meet all of the requirements for all of the aircraft types is probably going to weigh and cost too much and may well not be technically achievable. However, designing a different system for each aircraft type may also be very costly. To reduce the cost and still meet most of the requirements, a common baseline ejection system may be developed. Then for each of the aircraft types, modular components can be added as needed to meet the appropriate requirements. In addition, special attention must be paid to the frequency of occurrence of each requirement. For example, some of the requirements may be very stringent and drive the design of the ejection / escape system. However, this requirement may hardly ever occur in a real situation; therefore, the requirement must be weighed carefully against the frequency of occurrence.

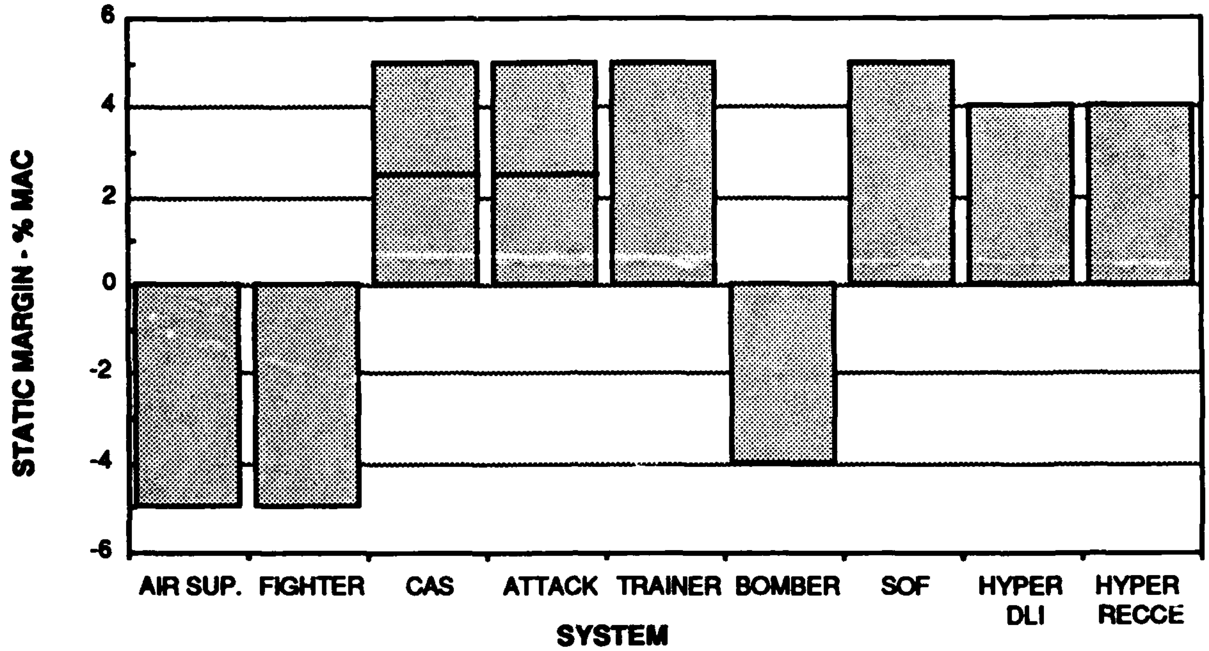


Figure 65
Static Margin Comparison

The general results and conclusions of this study are itemized below:

(1) The flight envelopes of the different aircraft classes can be broken into three distinct groups: subsonic, supersonic and hypersonic designs.

(2) Additional consideration must be given to the hypersonic aircraft due to the very high temperatures that are expected around the canopy.

(3) The load factor envelopes of the different aircraft classes are more mission dependent than speed dependent. That is, most fighter or attack aircraft have a much higher load factor limit than does a bomber or a transport aircraft.

(4) Terrain following operations are also a function of the mission. However, the speed and altitude of the penetration is highly dependent on the expected threats and the signature level of the aircraft.

(5) Takeoff and landing speeds do not vary significantly between the configurations with the exception of the hypersonic reconnaissance vehicle.

(6) Stability margins are very configuration dependent but are moving more towards unstable designs for combat aircraft to increase maneuverability. Other aircraft may use relaxed static stability to enhance the cruise performance.

2.3 Task 3 - Analysis of Third Generation Escape Systems Versus Future Aircraft Escape Requirements

2.3.1 **Introduction.** The performance capabilities of future aircraft as used in this study are based on the results of the Task 2 study performed by Rockwell International on seven aircraft. These seven aircraft are listed below.

(1) Air Superiority Fighter
(2) Multi-Role Fighter
(3) Close Air Support
(4) Attack Aircraft
(5) JPATS
(6) Strategic Bomber
(7) Special Operations

The U.S. Air Force aircraft emergency escape design guide, and the U.S. Air Force ejection seat specification, MIL-S-9479B, were used in this study to define the design goal to be met by the third generation escape systems. The CREST System Specification was used in this study as the existing design goal performance level for fourth generation escape systems.

The performance capabilities of third generation escape systems as presented in this study are based on the study performed by LME under Task 1 of this project. Unfortunately, the data available on these third generation escape systems does not cover certain areas of interest and best estimates have had to be made.

The Mach number versus altitude performance envelope was considered first. In this effort, future aircraft performance data were compared to the third generation specification requirements and to the CREST requirements. Then the Mach number versus altitude performance of the four third generation seats studied in Task 1 were compared to these aircraft and specification Mach/Altitude envelopes.

The possibility of ejected seat/man collision with either the wings or the empennage under severe high airspeed/very high roll rates was then considered. The aircraft which was considered as representing the most dangerous roll rate escape environment was studied so as to estimate the maximum roll rates at which third generation escape systems could still provide safe escape.

The maximum triaxial acceleration environments under which fourth generation escape systems may be called upon to provide safe escape have been defined in the CREST specification and are as follows:

- Gx - positive 2g (eyeballs in) and negative 3.5g
- Gy - positive 2g and negative 2g
- Gz - positive 5g (eyeballs down) and negative 4g

In general, ejection seat system tests under these environments have not been performed. However, some tests were performed by the U.S. Air Force on the ACES-II catapult under positive Gz conditions.

2.3.2 Third Generation Escape System Performance Versus Future Aircraft Requirements

2.3.2.1 **Mach Number/Altitude Capability.** The maximum dynamic pressure, maximum Mach number, and maximum altitude capability for the seven future aircraft to be studied are listed in Table XX. It is noted in this table that the only essential difference between the Attack Aircraft and the Air Superiority Fighter performance is its maximum flight altitude of fifty thousand feet versus sixty thousand feet, respectively. Because of this, only the Air Superiority Fighter Mach number versus altitude performance envelope is shown in Figure 66. In this figure it is readily seen that the third generation escape system design guide performance is deficient compared to the Strategic Bomber only in maximum altitude capability, but it is deficient compared to the Air Superiority Fighter and the Multi-Role Fighter in both the maximum altitude capability and in the maximum dynamic pressure capability. It is also noted that the CREST performance is deficient compared to the Multi-Role Fighter dynamic pressure capability.

Figure 67 includes data on third generation escape systems which is taken from Sections 2.1.2.6.1

through 2.1.2.6.5. These sections deal with the effects of supersonic normal shock waves on the seat mounted pressure sensors which cause them to read lower dynamic pressures (or lower airspeeds than actual) and greater static pressures (or lower altitudes than actual) which could result in premature parachute deployment in higher speed, high altitude ejections. These effects are depicted in Figures 2, 3, and 4. Figure 67 indicates that the third generation escape systems meet or exceed the projected performance requirements of the JPATS, Special Operations, Close Air Support and Strategic Bomber types of aircraft. In the case of the Strategic Bomber, a pressure suit for the crew members would be required since the Bomber's anticipated service ceiling of 60,000 feet exceeds the 50,000 feet human exposure limit. None of the third generation systems are capable of meeting the projected performance requirements of the Attack, Air Superiority Fighter, or the Multi-Role Fighter type of aircraft at low to medium altitudes. The Air Superiority Fighter and Attack type aircraft requirements can be met by the S4S at altitudes above 28,000 feet, by the ACES-II (or the ACES-II PLUS) above 35,000 feet and by the NACES above 41,000 feet. For the Multi-Role Fighter type aircraft the minimum altitudes for these third generation escape systems to provide acceptable performance are 33,000, 40,000 and 46,000 feet respectively. As can be seen in Figure 68, the third generation ejection seats do not meet the performance requirements of the Air Force Guide Specification (AFGS-87235A), or the CREST Specification.

2.3.2.2 High Airspeed, High Angular Rates Capability. The Air Superiority Fighter is considered to be the aircraft presenting the greatest hazard of seat/aircrewman contact with the empennage or wing under aircraft roll rates. Although the Strategic Bomber has much longer wings, they are much further down stream behind the crew station in the cockpit and, in addition, the maximum dynamic pressure for this aircraft is only forty percent of that of the Air Superiority Fighter. The Multi-Role Fighter wings are so short that even the higher dynamic pressure of this aircraft is not critical.

The ACES-II (or the ACES-II PLUS) ejection seat has the shortest catapult stroke and the smallest catapult separation velocity. This seat will have the slowest travel away from the aircraft centerline and thus be subject to wing tip contact under roll conditions for which the other third generation seats will be beyond the wing tip radius. The NACES seat has its sustainer rocket on the seat bottom with the smallest thrust angle forward of the seat guide rails. It is thus believed to be the seat which will have the most down wind travel behind the cockpit and have a higher probability of wing tip contact under roll and high dynamic pressure conditions. The other third generation seats would be more forward of the wing tip and have a lower probability of contact. Figure 69 provides a forward view of the ACES-II (or the ACES-II PLUS) seat escape trajectory of a 600 KEAS ejection out of the Air Superiority Fighter under the roll rate condition of 60 RPM (360 degrees per second) and Figure 70 is the same view for the roll rate condition of 120 RPM.

Table XX. Summary of Typical Future Aircraft Characteristics

SUMMARY OF TYPICAL FUTURE AIRCRAFT CHARACTERISTICS		AIR SUPERIORITY FIGHTER	MULTI-ROLE FIGHTER	CLOSE AIR SUPPORT	ATTACK	JPATS	STRATEGIC BOMBER	SPECIAL OPERATIONS
ROLL RATE (DEGREES/SEC)		128		69	69		20	32
MAXIMUM DYNAMIC PRESSURE (PSF)		1500	2100	1000	1480	300	600	800
MAXIMUM EQUIVALENT AIRSPEED (KEAS)		665	787	543	660	297	420	485
MAXIMUM MACH NUMBER		1.6	1.8	0.9	1.6	0.7	1.5	0.8
Q/MACH LIMIT TRANSITION (1000 FEET)		23.2	20.8	4.80	23.2	22.3	40.2	4.40
MAXIMUM ALTITUDE (1000 FEET)		60	55	40	50	45	60	40
MAXIMUM POSITIVE Gz		+9.0	+9.0	+7.5	+7.0	+7.0	+3.0	+3.0
MAXIMUM NEGATIVE Gz		-5.0	-4.0	-3.0	-3.0	-3.0	-1.0	-1.0
	X (FT)	36.5	21.0	17.9	19.9	1.32	129	
FWD EDGE OF WING TIP	Y (FT)	24.5	16.5	20.5	27.7	17.2	97.4	36.7
	Z (FT)							
	X (FT)	46.1	29.5	35.2	43.1	16.9		
UPPER FWD TIP OF VERTICAL TAIL	Y (FT)	8.96	11.3	9.45	7.97	0		13.8
	Z (FT)	10.2	8.50	10.5	12.9	6.62		22.9
	X (FT)					18.2		
FWD EDGE OF HORIZ. STAB. TIP	Y (FT)					6.12		
	Z (FT)					6.62		

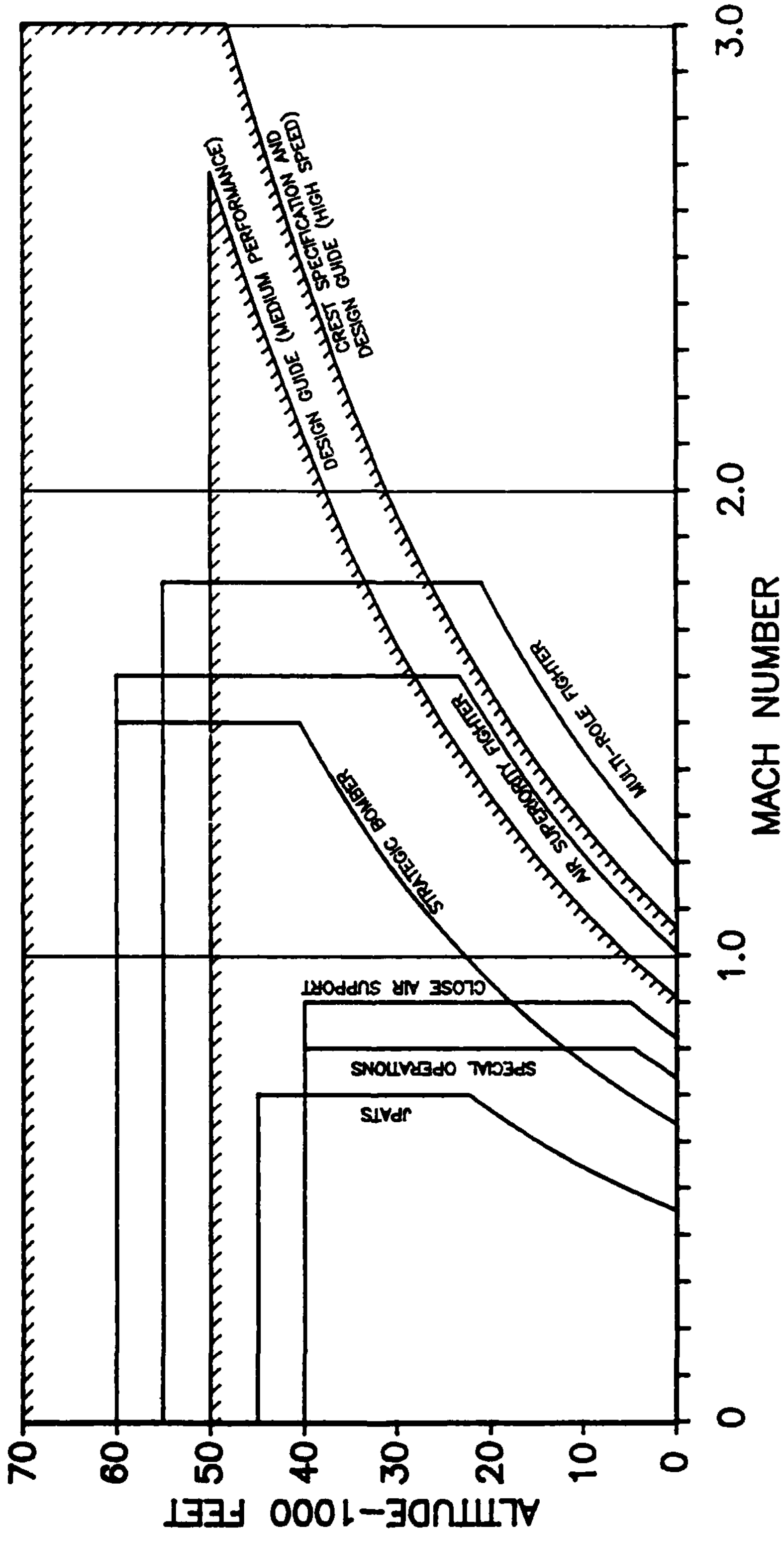


Figure 66
Future Aircraft and Specification Comparison

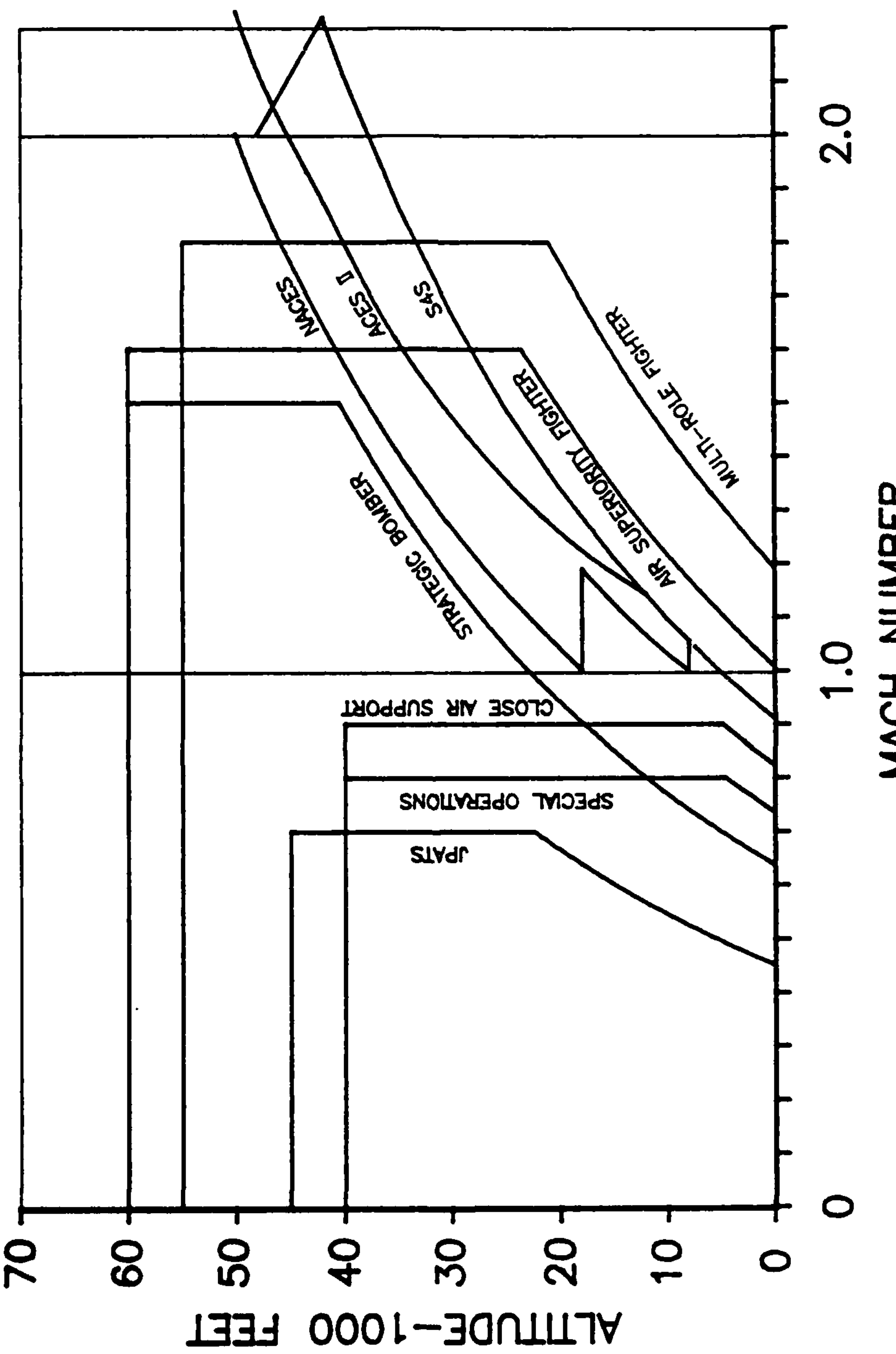


Figure 67
Third Generation Ejection Seats and Future Aircraft Performance Comparison

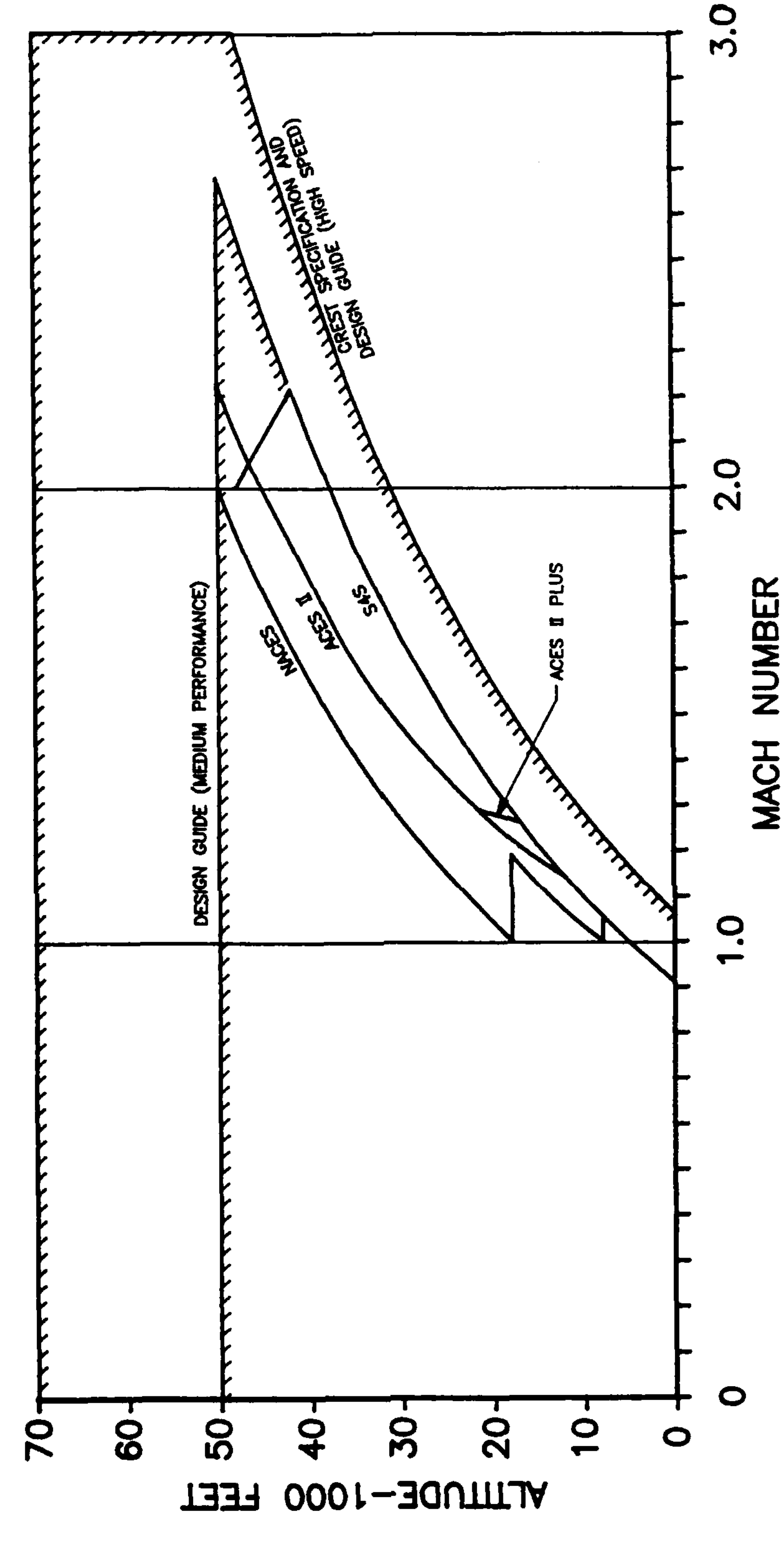


Figure 68
Third Generation Ejection Seats and Specification Performance Comparison

In Figure 69 it is seen from the trajectory that the ACES-II seat has passed well beyond the wing tip radius before the wing has time to rotate around to where it is in line with the escape trajectory (at about 0.51 seconds). In Figure 70 it is seen that the wing has rotated to where it is in line with the ACES-II seat escape trajectory at time equal about 0.31 second, but at that time the seat is about twenty-five feet forward of the wing tip. In Figures 71 and 72 the computed escape trajectories of the NACES seat are depicted under the same ejection airspeed and roll rate conditions. It is seen that the NACES seat is well beyond the wing tip radius or passes forward of the wing tip when the wing has rotated in line with the escape trajectory. From these figures it is concluded that even at airspeeds higher than 600 KEAS, roll rates below 120 RPM (720 DPS) are safe for ejection with third generation escape systems.

Aircraft yaw rates will not effect seat/man clearance of either the wing or the empennage of the Air Superiority Fighter.

For either a nose down or nose up pitch rate at a high airspeed the trajectory of the aircraft is a definite unknown as the probability of a wing structural failure is very great and the aircraft velocity decay before or after a wing failure is unknown. It does appear that there will be some nose down pitch angle/rate combinations which would cause the aircraft trajectory to cross that of the ejectee after the main recovery parachute has inflated.

2.3.2.3 Triaxial High Acceleration Conditions Capability. Negative Gx accelerations up to 3.5g can be experienced under low airspeed, arrested landing conditions. This ejection condition was tested by the Navy about twenty years ago using a sled traveling in the order of 50 KEAS at deceleration levels of one and three g's. The Escapac 1-A1 seat, upgraded with a pitch stability subsystem (DART), Snubber, External Pilot Chute and Ballistic Spreader Gun was the test unit. Even though the seat/dummy was ballasted to achieve a c.g. position two inches below its normal location as measured perpendicular to the thrust line, the tests were successful. An extremely low trajectory resulted, due to the high nose down pitch rates introduced by tipoff, extremely low center of gravity and sled deceleration. However, if the pitch stability subsystem had not corrected the high nose down pitch rates generated by the extreme test conditions, the trajectory would have been too low to achieve recovery. Thus, it is concluded that both the S4S and the ACES-II (or ACES-II PLUS), with the low speed pitch stabilization capabilities they possess, will meet the -3.5 Gx ground level ejection condition. It must be pointed out, however, that the inertia reel used in these two seats will not retract a pilot who is leaning forward in these negative Gx conditions and it is possible that the PCU-15 harness in the ACES-II seat would allow some submarining of the ejectee prior to catapult thrust onset.

The NACES, which does not incorporate low speed pitch stabilization in its design, can experience a nose down pitch rate at tipoff which can result in a low trajectory with a head first seat attitude at parachute deployment.

At high airspeeds, an aircraft deceleration environment tends to counteract the airstream nose up pitching tipoff inputs such that less severe nose up pitch attitudes would result. Thus, high airspeed/high deceleration ejection conditions will be less hazardous to the ejectee than the same high airspeed ejections in which high decelerations are not present.

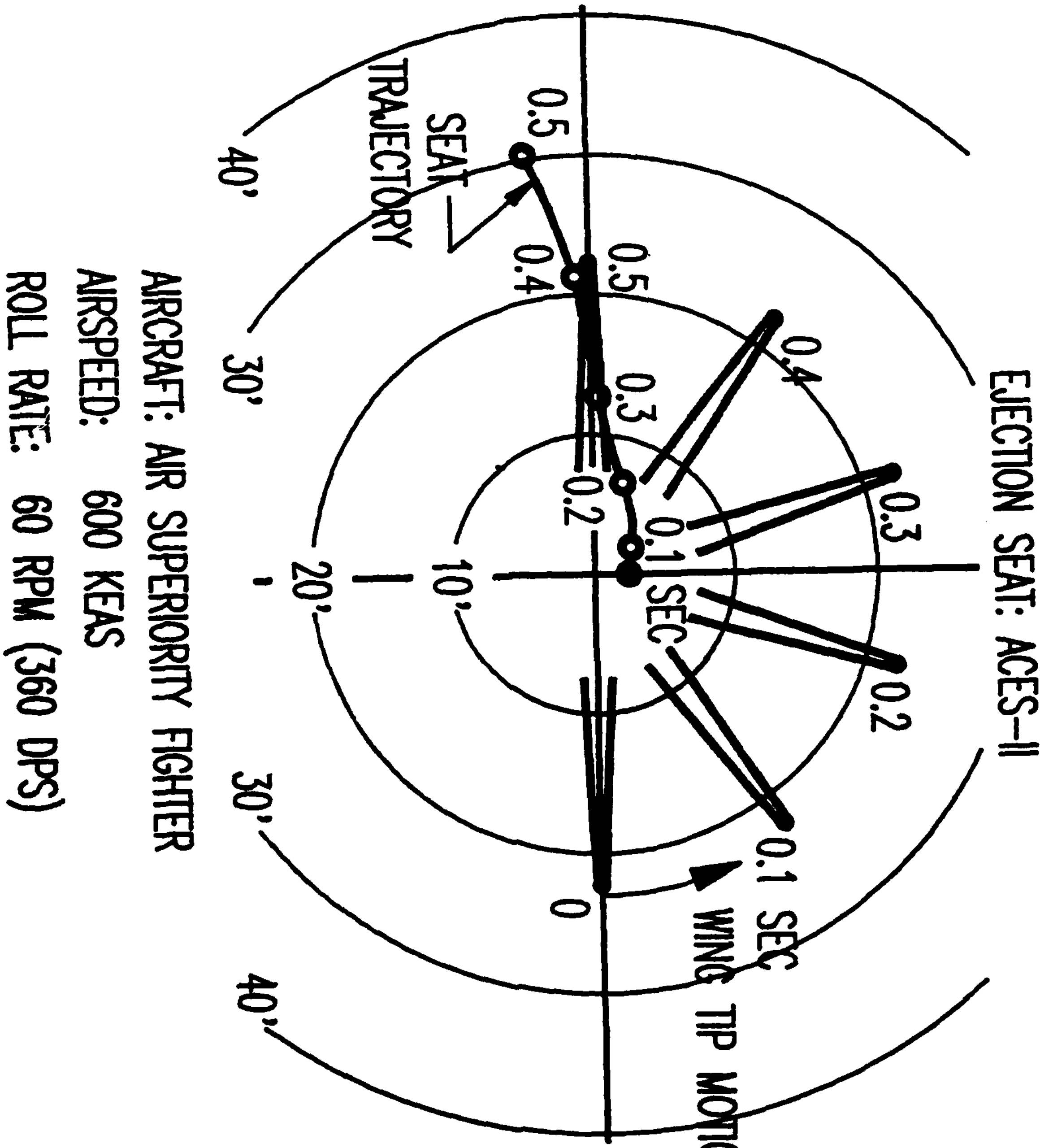


Figure 69
ACES-II 600 KEAS, 60 RPM Roll Escape Trajectory

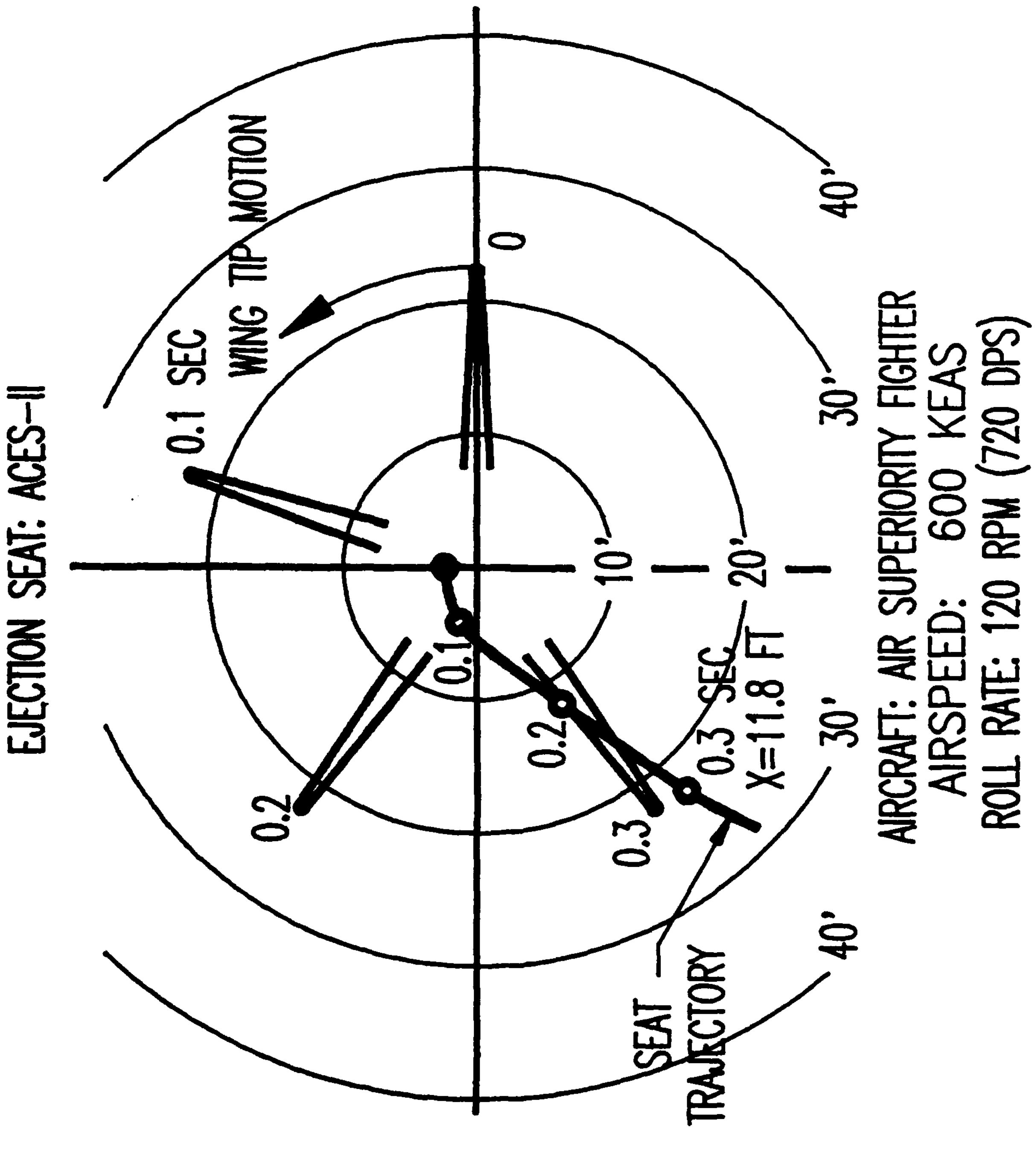


Figure 70
ACES-II 600 KEAS, 120 RPM Roll Escape Trajectory

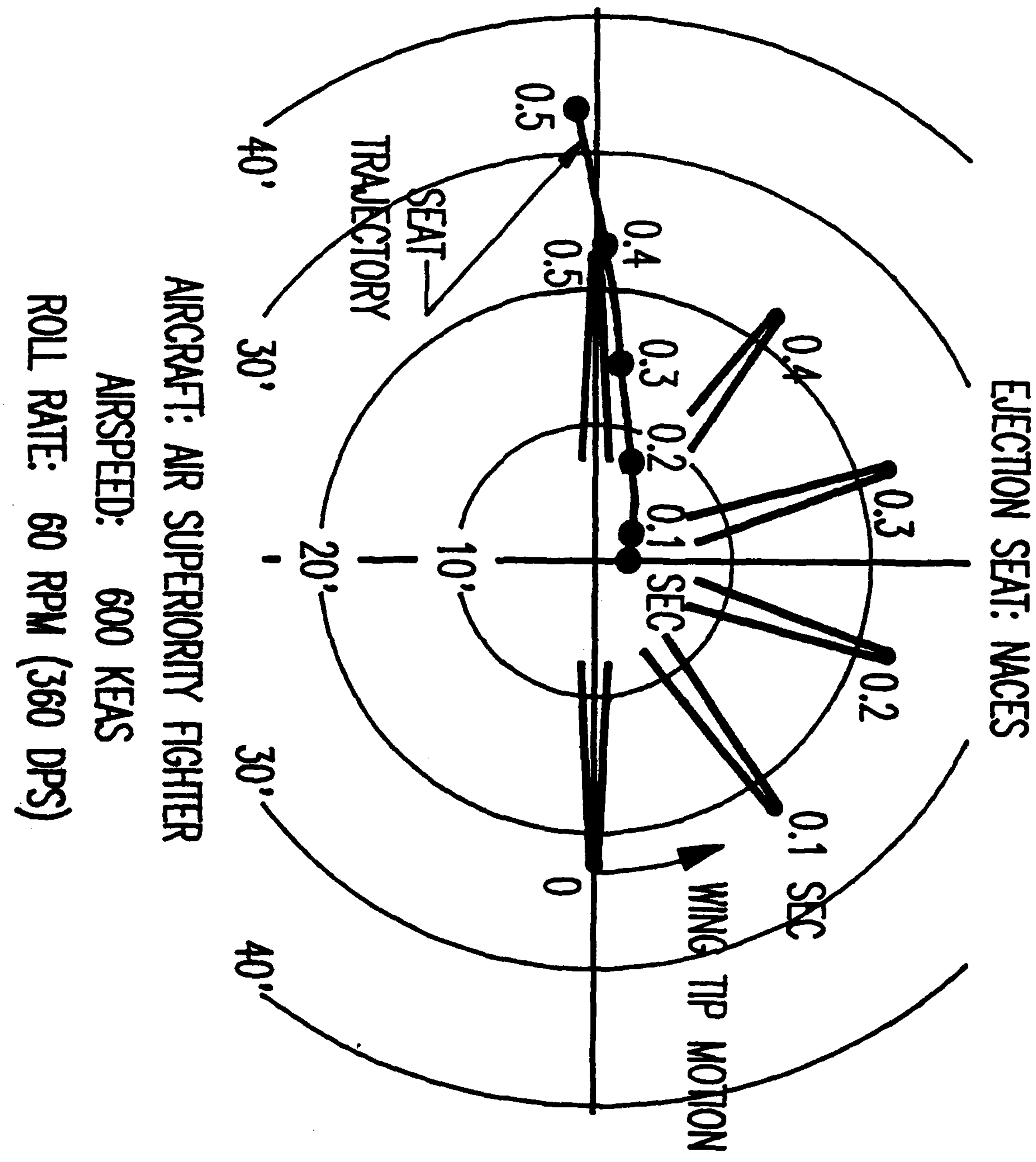


Figure 71
NACES 600 KEAS, 60 RPM Roll Escape Trajectory

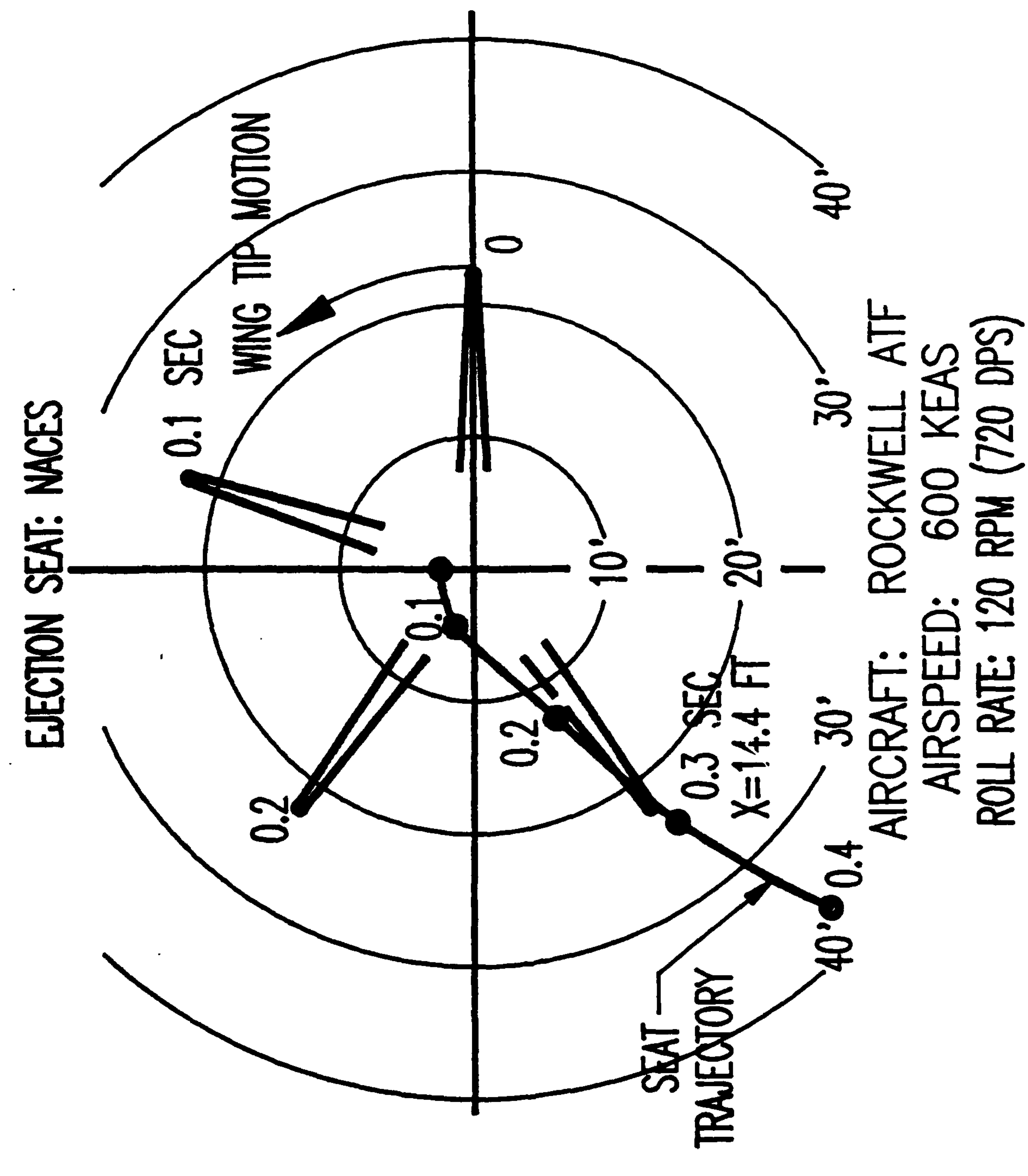


Figure 72
NACES 600 KEAS, 120 RPM Roll Escape Trajectory

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The positive Gx acceleration is limited by the ratio of the forward thrust of the aircraft engine(s) divided by the weight of the aircraft. A value of 2g's has been considered to be a reasonable limit even for the next generation aircraft. At maximum airspeed conditions the total engine thrust is being used to maintain the airspeed and a positive Gx acceleration can not be experienced under these high airspeed conditions. Any drag on the aircraft will reduce the maximum Gx acceleration which the engine(s) can produce. Thus only at very low flight speeds can such high Gx accelerations be generated and in this environment a positive Gx acceleration will tend to reduce the nose down tipoff pitch rate which is normal for such low speed ejections.

Lateral accelerations of 2g's are not considered to be a problem for any of the third generation escape systems. It is unknown if ejection system tests have ever been performed on any ejection seat under such lateral accelerations.

A negative Gz acceleration of 4 g's will produce an upward movement of a pilot off the seat pan. The ACES-II (or the ACES-II PLUS) and the current NACES have upward restraint provided by the lap belt, which allows the spine to elongate under these negative Gz accelerations. Upon ejection in this condition the seat can impact the base of the ejectee's spine with a velocity that may be injurious. The unqualified IH-1 harness provides over-the-shoulder restraint which will reduce the upward head movement appreciably as compared to other restraint harnesses, but will not totally prevent upward movement of the buttocks off the seat pan. Since no tests have been performed in this negative Gz condition, it is not possible to evaluate the injury potential to an ejectee produced by such accelerations. It is likely, however, that there is injury potential in an ejection under a 4g negative Gz acceleration when using any of the third generation escape systems.

A positive Gz acceleration of 5g's will act to push the seat occupant's body downward against the seat pan and ejecting under this acceleration environment will result in an increased loading of the spine. Actual tests performed on the ACES-II catapult under positive Gz accelerations up to or greater than 5g's resulted in unacceptably high DRI values (> 30). Although such tests have not been performed on the other third generation escape system catapults, it must be assumed that they also will not provide safe egress from the aircraft cockpit under a 5g's positive Gz acceleration ejection environment.

2.3.2.4 Maximum Dynamic Pressure Conditions. The Multi-Role Fighter type of aircraft has a maximum dynamic pressure capability of 2100 PSF. No third generation escape system will provide safe escape under these extreme dynamic pressure conditions. Nose up tipoff will result in large nose up pitch angles of ninety degrees or more. Early deployment of the drogue will result in an extremely high deceleration level of greater than 40 g's which will separate the ejectee's head from the headrest and dangerous shear and tension neck loads are likely.

2.3.2.5 Estimated Ejection Limits for Aircrew Personal Protection Equipment. The capabilities of current aircrew personal protection equipment have been studied to estimate the limits of protection provided against the hazards of high altitude, high speed escape in an open ejection seat. The results of this study are shown graphically in Figure 73. It should be noted the limits shown in Figure 73 are not operational altitudes permitted to complete a mission in the event of an emergency but one for escape only.

The escape limits of the current aircrew personal protection equipment were then compared to the performance envelopes of the future aircraft listed in Table XX to determine the equipments capability to provide the necessary levels of protection for a safe ejection of a crewmember throughout the future aircraft performance envelopes.

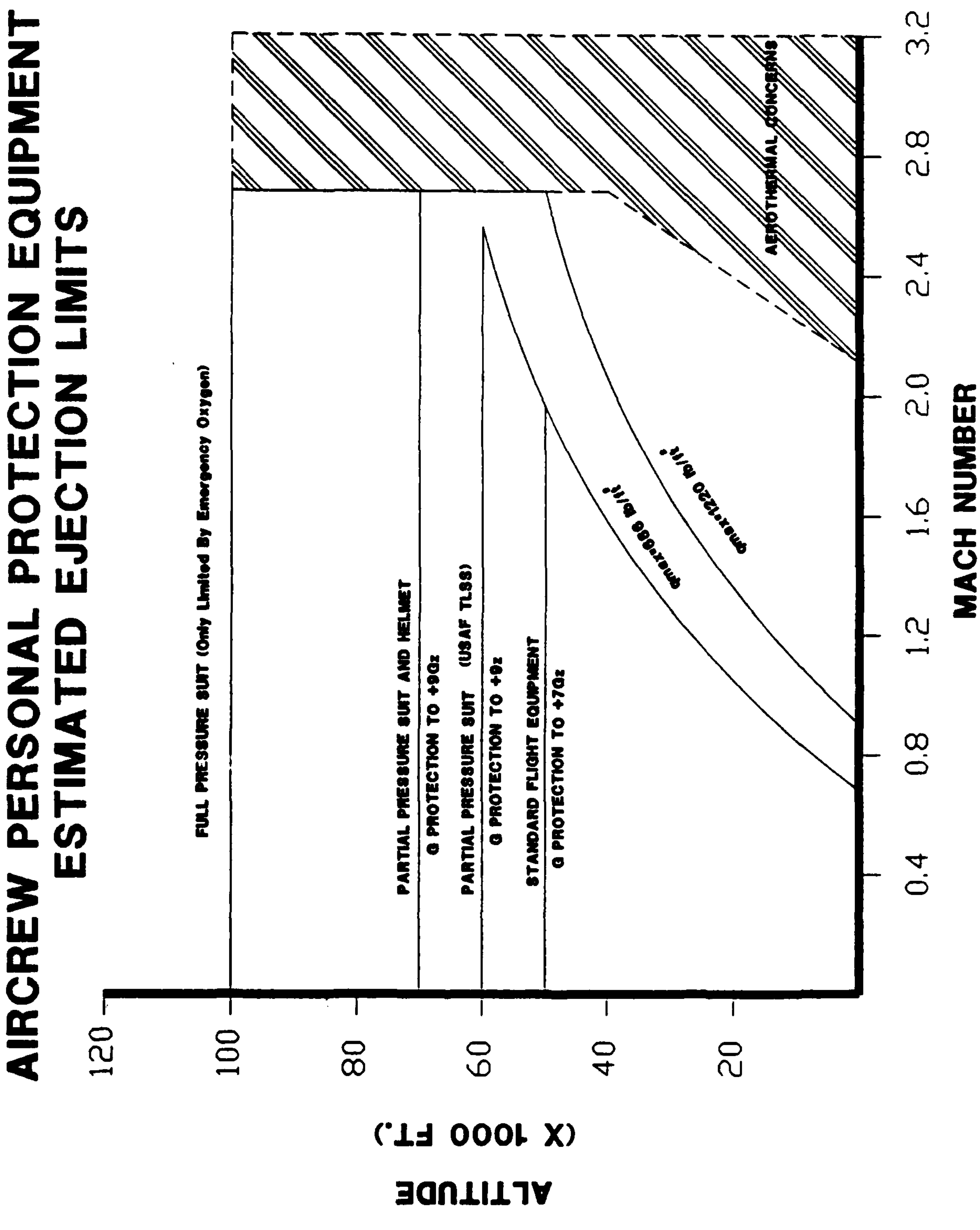

Figure 73
Aircrew Personal Protection Equipment Estimated Ejection Limits

Hazards to which aircrewmembers will be exposed in escape from future aircraft in an open ejection seat results from either altitude or speed. The hazards to which aircrewmembers will be exposed during a high speed ejection are dynamic pressure and aerothermal heating. The hazards associated with a high altitude ejection are hypoxia, decompression sickness and hypothermia. Current aircrew personal protection equipment were evaluated against these hazards.

Three types of aircrew personal protection equipment were studied. These included the standard aircrew personal protection equipment supplied to fighter, attack and bomber squadrons in the U.S. Air Force and Navy, Partial Pressure Suits such as the USAF Tactical Life Support System (TLSS), the French VHA-90 Series ensemble and the Northrop Advanced Protection System (APS), and Full Pressure suits such as the S1030 used by SR-71 flight crews.

The primary difference between the three types is the level of pressure coverage over the body and level of pressure breathing delivered to the respiratory. It is these levels of pressure that will determine to what altitude the aircrewmember is protected against the hazards associated with high altitude flight, specifically hypoxia and decompression sickness.

The hazards associated with escape and high speeds are dynamic pressures and aerothermal heating. Dynamic pressure (windblast) is the one hazard for which current aircrew personal protection equipment (with the exception of a full pressure suit) is deficient in providing the necessary levels of protection during escape in an open ejection seat from the aircraft in Table XX. The threshold of injury from dynamic pressure probably lies at about 4.5 psi (650 PSF), and severe damage is probable at about 9 psi (1300 PSF) for the unprotected human. If the above stated threshold values are reasonable, then, current aircrew personal protection equipment may not provide sufficient lower body, head and neck protection for use in the future Multi-Role Fighter, Air Superiority Fighter and Attack Aircraft.

The major deficiency with the standard and partial pressure aircrew protection equipment is the level of head and neck protection provided by the standard flight helmet and oxygen mask currently in use. The USAF and USN standard flight helmets are the HGU-55/P and HGU-68/P respectively. The oxygen masks in use are the MBU-12/P and soon to be used MBU-20/P or equivalent. Current specifications (MIL-H-87174 (USAF) and MIL-H-85047 AS (USN)) require that the helmet/visor/0_2 mask remain structurally intact when subjected to a windblast of 450 KEAS (686 PSF). Recent windblast tests have shown that the current helmet/0_2 mask configurations remain structurally intact when subjected to windblasts up to 600 KEAS (1220 PSF). However, this has not been established as the requirement. The current equipment will in all probability not remain structurally intact when subjected to the maximum dynamic pressure encountered during escape from the future Air Superiority Fighter (q max 1500 PSF), Multi-Role Fighter (q max 2100 PSF) and Attack Aircraft (q max 1480 PSF).

Even if the structural integrity concerns of the current standard helmet/visor/0_2 mask were satisfied, there still exists a high probability of neck injury during escape from an aircraft with speeds in excess of 450 KEAS using current ejection seats. The primary contribution to neck injury results from the current method of helmet retention. For current standard flight helmets (HGU-55/P) and those partial pressure systems which do not use a pressure helmet retention is accomplished by a chin and nape strap which reacts the helmet aerodynamic and acceleration induced loads through the neck. Wind tunnel test programs using the USAF half-scale, 50th percentile male dummy seated in the ACES II half-scale seat, were performed to measure head/neck loads. The maximum neck tension recorded at an airspeed of 600 KEAS and 0 pitch was 583 lbs.

According to guidelines developed by General Motors, neck injury is likely to occur if axial tension exceeds 250 lbs for 45 msec. A significant reduction in neck axial tension loads will result when a full pressure suit or partial pressure suit with a pressure helmet is used. The reduction is accomplished in the way the helmet is integrated into the system. Pressure helmets require a neck ring or hold down cable system to carry the helmet loads directly into the torso of the crewmember, thereby greatly reducing the risk of neck injury due to axial tension on the neck.

The boundary of aerothermal concern shown in Figure 73 is a conservative estimate and was established where the stagnation temperature around the crewmember exceeded 400 F. It is believed the current aircrew personal protection equipment is capable of providing protection against aerodynamic heating at speeds in excess of that shown in Figure 73. Exposure times at these elevated temperatures will be of a very short duration. The 400-500 F limit was established by the temperature limitations of the materials used in the manufacture of the aircrew personal protection equipment. It is doubtful that injury resulting from burns will occur at the limits shown in Figure 73. The conservative limits were established

due to the unavailability of data and, an indepth analysis of exposure duration, heat flow and heat transfer were beyond the scope of this task.

The hazards during escape at high altitudes (above 60,000 feet) are hypoxia, decompression sickness and hypothermia. The altitude limitations of current aircrew personal protection equipment for escape are shown in Figure 73.

Severe and unacceptable hypoxia follows within a few seconds of exposure to altitudes above 40 to 43 thousand feet even when 100 percent oxygen is breathed. Thus, whether the duration of exposure to high altitude is short (during escape) or long, protection against hypoxia must be provided. Recent testing of the USAF Tactical Life Support System (TLSS) up to 60,000 ft altitude has demonstrated it can provide the necessary protection from the altitude hazards a crewmember will encounter during escape from all the future aircraft listed in Table XX. The TLSS employs a high pressure mask capable of delivering breathing pressures in the 50-70mm Hg range, a pressure jerkin and a standard CSU-13/P Anti-G suit. It is this combination of equipment that provides the crewmember with the necessary protection against the physiological effects of hypoxia during escape or get-me-down maneuvers up to 60,000 feet.

The incidence of decompression sickness only becomes significant when the crewmember is exposed to altitudes pressures above 30,000 feet for approximately 10 minutes. The maximum operational altitude of the future aircraft in Table XX is 60,000 feet. Free fall descent from 60,000 feet to 30,000 feet during an ejection would take less than 2 minutes which is significantly less than the 10 minute exposure permitted before decompression sickness becomes a significant hazard. In addition, studies on monkeys and chimpanzees suggest that exposures to a virtual vacuum for 1.5 to 2 minutes is very unlikely to be fatal or give rise to any neurological change. As a result of these findings, decompression sickness presents little to no physiological hazard when ejecting from an aircraft with a maximum ceiling of 60,000 feet with no additional protection other than that afforded by current standard aircrew personal protection equipment.

Short duration exposure to the low ambient temperatures, as would be encountered in a high altitude escape, will not cause serious impairment of performance or serious damage to subjects wearing current standard aircrew personal protection equipment. Current standard aircrew personal protection equipment when used in conjunction with current anti-exposure clothing will provide the necessary protection against hypothermia and skin injury from cold when escaping from the future aircraft listed in Table XX.

2.3.3 Conclusions. It is concluded that no third generation escape system will provide safe escape from future high performance aircraft with the performance levels predicted for the Attack, Air Superiority Fighter and Multi-Role Fighter type of aircraft. The upgrades which have been proposed to date do not appear to have improved the negative and positive Gz capability nor to have improved the Mach No. immunity sufficiently to give assurance of safe escape up to the levels required by these three future aircraft. However, they do appear to provide sufficient escape performance levels for the JPATS, Special Operations, Close Air Support and Strategic Bomber future aircraft. Comparing the ejection limits of current aircrew personal protection equipment (Figure 73) with the projected performance characteristics of future aircraft (Table XX) demonstrates the current aircrew personal protection equipment is deficient in providing the necessary levels of protection for a safe escape throughout the entire performance envelope of the Future Air Superiority Fighter, Multi-Role Fighter and Attack Aircraft.

2.4 Task 4 - Current and Future Crew Escape Requirements

2.4.1 Introduction. This report documents the efforts conducted by LME for Task 4. The objective of this task was to compare the escape system requirements of future high performance aircraft with the capabilities of fourth generation escape systems. Earlier efforts by LME under Tasks 1 and 3 were used under this task..

2.4.2 System Requirements Evaluation. The performance capabilities of future aircraft as used in this study are based on the results of the study performed by Rockwell International under Task 2 of this program. Table XXI summarizes the pertinent data on the seven aircraft listed below:

(1) Air Superiority Fighter
(2) Multi-Role Fighter
(3) Close Air Support
(4) Attack Aircraft
(5) JPATS
(6) Strategic Bomber
(7) Special Operations

The CREST System Specification and the USAF Guide Specification were used in this study to define the design goal performance levels for fourth generation escape systems. Figure 74 illustrates the future aircraft performance capabilities versus the fourth generation escape system performance requirements.

2.4.2.1 In-flight Accelerations. The maximum acceleration environments under which fourth generation escape systems may be called upon to provide safe escape have been defined in paragraph 3.2.1.1.3 of the CREST specification and are as follows:

Gx - positive 2g (eyeballs in) and negative 3.5g
Gy - positive 2g and negative 2g
Gz - positive 4g (eyeballs up) and negative 5g

2.4.2.1.1 Longitudinal. Task 2 did not present any predictions for longitudinal accelerations of the future aircraft but it seems reasonable to assume that they will not exceed those anticipated by the CREST Specification.

2.4.2.1.1.1 Negative Gx. At high airspeeds, an aircraft deceleration environment tends to counteract the nose up pitching moments produced by the dynamic pressure with a net effect such that less severe nose up pitching rates and attitudes would result. Thus, high airspeed/high deceleration ejection conditions will be less hazardous to the ejectee than the same high airspeed ejections in which high decelerations are not present. At zero or very low speeds, however, the nose down pitching moments produced by aircraft decelerations will be additive to those created by the ejected mass center of gravity/catapult thrust line eccentricity. Thus, the high negative Gx/low airspeed ejection case will be one of the determining conditions for the trajectory control to be provided by the controllable rocket thrust vector.

Table XXI. Summary of Typical Future Aircraft Characteristics

SUMMARY OF TYPICAL FUTURE AIRCRAFT CHARACTERISTICS	AIR SUPERIORITY FIGHTER	MULTI-ROLE FIGHTER	CLOSE AIR SUPPORT	ATTACK	JPATS	STRATEGIC BOMBER	SPECIAL OPERATIONS
ROLL RATE (DEGREES/SEC)	128	.	69	69		20	32
MAXIMUM DYNAMIC PRESSURE (PSF)	1500	2100	1000	1480	300	600	800
MAXIMUM EQUIVALENT AIRSPEED (KEAS)	665	787	543	660	297	420	485
MAXIMUM MACH NUMBER	1.6	1.8	0.9	1.6	0.7	1.5	0.8
Q/MACH LIMIT TRANSITION (1000 FEET)	23.2	20.8	4.80	23.2	22.3	40.2	4.40
MAXIMUM ALTITUDE (1000 FEET)	60	55	40	50	45	60	40
MAXIMUM POSITIVE Gz	+9.0	+9.0	+7.5	+7.0	+7.0	+3.0	+3.0
MAXIMUM NEGATIVE Gz	-5.0	-4.0	-3.0	-3.0	-3.0	-1.0	-1.0
X (FT)	36.5	21.0	17.9	19.9	1.32	129	
FWD EDGE OF WING TIP Y (FT)	24.5	16.5	20.5	27.7	17.2	97.4	36.7
Z (FT)							
X (FT)	46.1	29.5	35.2	43.1	16.9		
UPPER FWD TIP OF VERTICAL TAIL Y (FT)	8.96	11.3	9.45	7.97	0		13.8
Z (FT)	10.2	8.50	10.5	12.9	6.62		22.9
X (FT)					18.2		
FWD EDGE OF HORIZ. STAB. TIP Y (FT)					6.12		
Z (FT)					6.62		

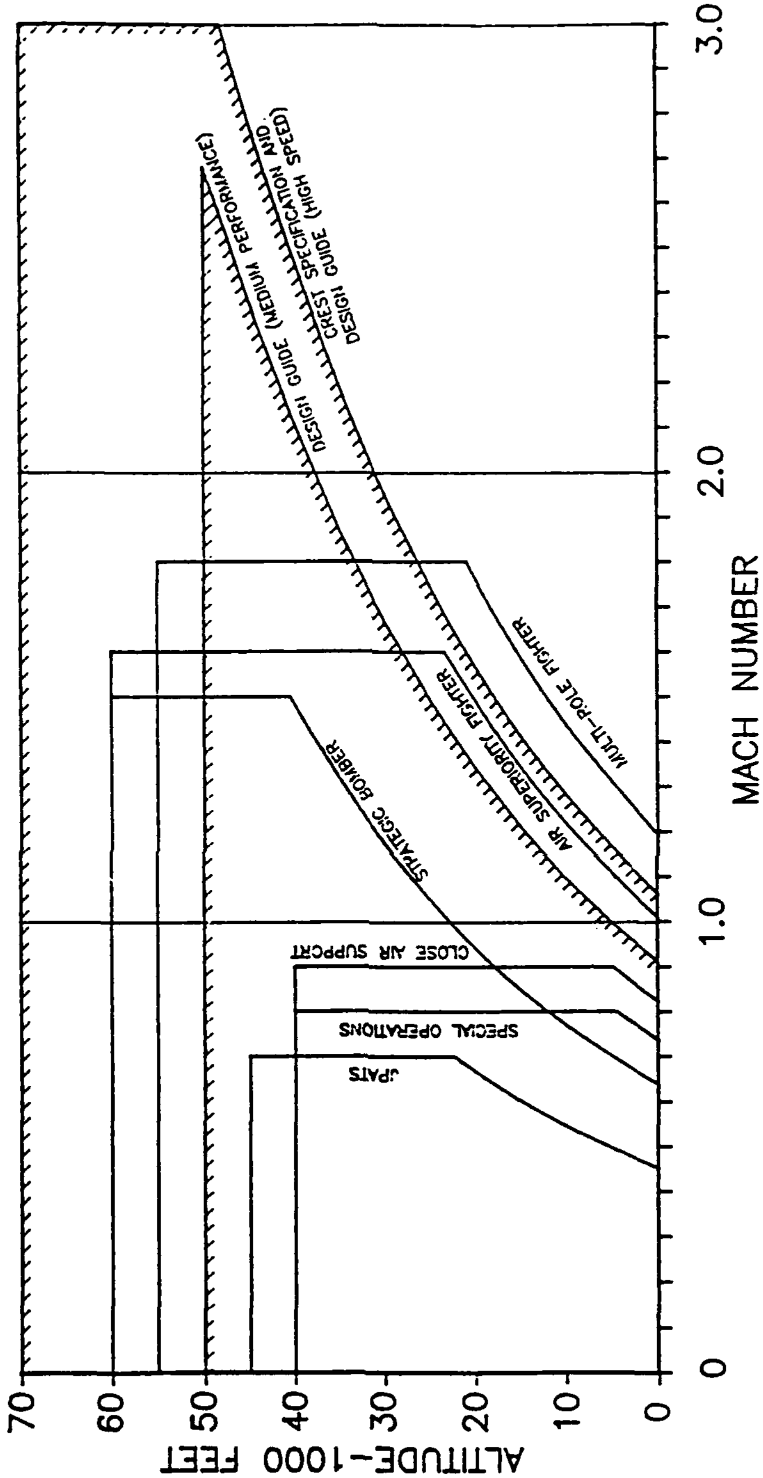

Figure 74
Future Aircraft and Specification Performance Comparison

2.4.2.1.1.2 Positive Gx. The positive Gx acceleration (eyeballs in) is limited by the ratio of the forward thrust of the aircraft engine(s) divided by the weight of the aircraft. A value of 2g's is considered to be a reasonable limit even for the next generation aircraft. At maximum airspeed conditions, the total engine thrust is being used to maintain the airspeed and a positive Gx acceleration can not be experienced under these high airspeed conditions. Any drag on the aircraft will reduce the maximum Gx acceleration which the engine(s) can produce. Thus only at very low flight speeds can such high Gx accelerations be generated and in this environment a positive Gx acceleration will tend to reduce the nose down pitch rate which is normal for such low speed ejections due to the c. g./ catapult thrust line offset.

2.4.2.1.2 Lateral. Task 2 did not provide any predictions of the lateral acceleration capabilities of the future aircraft. It is assumed that they will not exceed the CREST requirements. Accelerations of 2g's laterally are not considered to be a problem.

2.4.2.1.3 Vertical. Positive and negative vertical acceleration capabilities for future aircraft were predicted in Task 2 and are summarized in Table XXI. Note that the sign convention used in Task 2 and in the table are opposite that used in the CREST specification.

2.4.2.1.3.1 Positive Gz. The Air Superiority Fighter is expected to be capable of producing eyeball up accelerations of 5 G's whereas the specification requires a maximum of only 4 G's. Positive Gz accelerations (eyeballs up) will tend to produce an upward movement of a pilot off the seat. The restraint system must be required to prevent any such motion or limit it to an amount found to be physiologically tolerable (see paragraph 2.4.3.7).

2.4.2.1.3.2 Negative Gz. Five of the seven aircraft discussed in Task 2 are expected to be capable of pulling g's in the eyeballs down direction in excess of the 5.0 g's maximum in the CREST Specification with the Air Superiority and Multi-Role Fighters expected to be the highest at 9.0 G's (see Table XXI). Negative accelerations (eyeballs down) will push the seat occupant's body downward against the seat and ejecting under this acceleration environment will result in an increased loading of the spine. With a controllable thrust catapult, however, the system could and should meet the performance capabilities of the aircraft (see paragraph 2.4.3.6.1). Even with a controllable catapult, the velocity produced by the catapult will be reduced significantly when ejection occurs under negative Gz accelerations since the "high risk" DRI values cannot be exceeded. The decrease in catapult velocity will result in reduced and, in some cases, inadequate tail clearance for some aircraft configurations for certain airspeed and Gz combinations.

2.4.2.2 Mach Number and Altitude. The maximum dynamic pressure, maximum Mach number, and maximum altitude capability for the seven future aircraft to be studied are listed in Table XXI and shown graphically in Figure 74. It is noted in this table that the only essential difference between the Attack Aircraft and the Air Superiority Fighter performance is its maximum flight altitude of fifty thousand feet versus sixty thousand feet, respectively. Because of this, only the Air Superiority Fighter Mach number versus altitude performance envelope is shown in Figure 74. In this figure it is readily seen that the escape system design guide medium performance requirements are adequate for the JPATS, Special Operations and Close Air Support aircraft and deficient for the Strategic Bomber only in the maximum altitude capability. These requirements do not satisfy the Air Superiority Fighter or the Multi-Role Fighter maximum altitude and maximum dynamic pressure performance requirements. The design guide high performance and the CREST performance requirements specify a maximum dynamic pressure (1660 PSF) that is compatible with the Air Superiority Fighter capabilities (1500 PSF), but less than that anticipated for the Multi-Role Fighter (2100 PSF).

2.4.2.3 Angular Velocity. Paragraph 3.2.1.1.4 of the Air Force Guide specifies the maximum angular rates that may occur individually during the ejection process. These rates are:

(1) 0.2 rps in pitch
(2) 0.1 rps in yaw
(3) 1.0 rps in roll

The list of abbreviations and symbols of the CREST Specification does not include "rps" but it is assumed herein to mean "revolutions per second" and not "radians per second". The maximum angular velocity capability of the escape system should meet or exceed the aircraft capabilities. The airspeed at which the various maximum angular rates occur should be specified or the requirements should be presented graphically with the rates as a function of airspeed. In order for the ejection seat designer to demonstrate (analytically) that the system will provide adequate aircraft clearance over the entire flight envelope, these requirements must be identified.

2.4.2.3.1 Pitch Rate. Task 2 does not specify the maximum pitch rate for any of the seven aircraft studied.

2.4.2.3.2 Yaw Rate. Task 2 does not specify the maximum yaw rate for any of the seven aircraft studied.

2.4.2.3.3 Roll Rate. The maximum roll rate discussed in Task 2 was 128 degrees per second (0.36 revolutions per second) predicted for the Air Superiority Fighter. An analysis was performed under Task 3 of this program in which it was concluded that even third generation ejection seats would provide adequate wing clearance in ejections occurring with roll rates as high as 2.0 revolutions per second at an airspeed of 600 KEAS. This analysis is presented in Task 3. It is presumed that fourth generation ejection seats will have catapult and trajectory control devices superior to those of the third generation ejection seats and will therefore provide even greater clearances.

2.4.3 Subsystems Requirements Evaluation. The subsystem requirements for fourth generation ejection seats as specified in the CREST Specification are evaluated for compatibility with the future aircraft requirements identified in Task 2 in the following paragraphs. Some of the comments made in the following paragraphs apply to high performance ejection seat requirements in general and do not necessarily relate to specific requirements of future aircraft as presented in Task 2.

2.4.3.1 Structure

2.4.3.1.1 Windblast. Paragraphs 3.2.1.1, 3.2.2.3.1 (e) and 3.2.7.1 of the CREST Specification require the subsystems to be structurally capable of withstanding dynamic pressures of 1660 PSF (a "windblast" of 700 KEAS). This requirement is satisfactory for all of the future aircraft performance capabilities of Task 2 except the Multi-Role Fighter which is anticipated to be capable of dynamic pressures of 2100 PSF (787 KEAS). Table XXI summarizes the contemplated maximum dynamic pressure for the various types of aircraft.

2.4.3.1.2 Accelerations. In defining the limit load requirements for the ejection seat, paragraph 3.2.2.3.1.b of the CREST Specification specifies that the inertial loads shall include the acceleration conditions and dynamic response characteristics of the 99th percentile personnel. Paragraph 3.2.2.3.2 defines the ultimate loads as the limit loads multiplied by a factor of safety of 1.50. The acceleration levels specified in the CREST Specification are summarized as follows:

CREST spec. paragraph number	3.2.1.1.3	3.7.2.4.3
Mission Phase	Ejection	In-flight
X-axis acceleration (eyeballs in)	+2.0g	+6.0g
X-axis acceleration (eyeballs out)	-3.5g	-6.0g
Y-axis acceleration (right or left)	+/-2.0	+/-2.0g
Z-axis acceleration (eyeballs up)	+4.0g	+4.0g
Z-axis acceleration (eyeballs down)	-5.0g	-10.0g

Multi-axis combinations of accelerations are not stipulated in the specification. Gx and Gy for future aircraft are not forecast in the data presented in Task 2, but the Air Superiority Fighter, Multi-Role Fighter, Close Air Support, Attack and JPATS type aircraft are all expected to be capable of Z-axis accelerations

(eyeballs downward) in excess of 5 G's and the Air Superiority Fighter is expected to be capable of imposing eyeball upward accelerations greater than 4 G's. Table XXI summarizes the predicted Gz capabilities for the various types of aircraft.

2.4.3.1.3 Crash Loads. Paragraph 3.2.2.3 of the CREST Specification requires the system to be capable of withstanding the crash load factors specified in Table I of MIL-A-008865A (USAF). This specification was canceled after the CREST Specification was written. Crash conditions for future aircraft will be no different than that of contemporary aircraft, but the specification should include the magnitude and direction of the design load factors.

2.4.3.2 Initiation. Paragraphs 3.1.4.1.1 and 3.7.1.1.1 of the CREST Specification require the ejection process to be initiated by mechanisms and ballistics contained within the seat which are activated by pulling one or both "side-arm controls". Task 2 and Appendix E recommend the incorporation of an automatic initiation system which would eject the aircrew when the aircraft's data and on-board computer recognize non-recoverable circumstances. (This can be used in conjunction with planned technologies involving aircraft automatic recovery systems). Such a system would not only recognize a requirement to eject much quicker than the aircrew in most cases, but would be the only method in cases where the aircrew have become incapacitated due to excessive G's or other causes. A system that is operational in Soviet YAK-36 and YAK-38 aircraft is discussed in the article "Soviet Ejection Seat for Buran Shuttle Qualified at Up to Mach 4" (Aviation Week, June 10, 1991), and by James Brinkley in a trip report documenting discussions with representatives of the Zvezda Design Bureau of the former Soviet Union (Brinkley, 1990). Although it is recognized that a large segment of the pilot community resists such schemes (as did the Soviets), there is no doubt that the incorporation of an automatic initiation system would save lives in contemporary as well as future aircraft.

2.4.3.3 Sensing. Numerous paragraphs in the CREST Specification refer to "sensors". Paragraph 3.1.1.11 describes the sensors as "Inertial sensor unit (accelerometers and rate gyros), pitot tubes, and radar altimeter". The purpose of the sensors is to "Provide aircraft, seat, and crewmember position, rate, and acceleration data". Subparagraphs to paragraph 3.1.4.1 include the "sensors" in the windblast protection, acceleration protection, emergency life support, ejection, trajectory and stability control, descent, seat/man separation and normal aircraft flight operation functions. Which data is used for each function is left to the system designer.

2.4.3.3.1 Pitot-Static Measurement Unit. The Phase I Final Report for CREST indicates that the initial design of the CREST utilized the pitot and static pressure measurements "for flight control and sequencing functions" (Herndon, et al, 1986). Although pitot-static probe concepts such as that described in the Brinkley trip report are intended to be deployed to a position in the "free airstream", it is questionable whether finite measurements of total or static pressure can be made in the pressure field generated by a blunt shape such as an ejection seat and its occupant at supersonic speeds. For example, data presented in the Phase I report indicate that "pitot probe coefficients" vary from 1.0 to 1.4 as the Mach Number is varied from 0.4 to 1.2. The pitot tube location on the seats used in these tests (full-scale ACES II) is aerodynamically similar to that of the CREST concept. Using such data for "risk assessment" or event sequencing while supersonic requires technology which is not available in the open literature. Techniques such as comparison of successive static pressure readings to detect supersonic conditions and structuring the software to "idle" until subsonic conditions are reached can be utilized, however.

2.4.3.4 Timing and Control. Paragraphs 3.1.1.6 and 3.1.1.7 require that the timing and control of the various escape system functions be controlled by a computer program which provides the logic to a microprocessor with its power supply and initiator firing control unit. With this concept, the software should be capable of providing the control required in the escape systems of the future aircraft and could easily be customized for a particular type of aircraft.

2.4.3.5 Signal Transmission. The following referenced paragraphs specify requirements for electrical signal transmission systems. Other types of signal transmission methods are not specifically disallowed, but no requirements are given except for the marking of lines (paragraph 3.3.3.2 of the

CREST Specification). None of the requirements are found to be incompatible with escape systems for future aircraft.

2.4.3.5.1 Aircraft Flight Data. Paragraph 3.1.5.1.2 of the CREST Specification requires electrical connection to aircraft data systems through connection to the central data bus (MIL-STD-1553 multiplex data bus).

2.4.3.5.2 Use of Aircraft Electrical Power. Paragraph 3.1.5.1.3 of the CREST Specification allows use of aircraft electrical power. Elements using this power are required to be operational over 22 to 32 VDC (28 VDC nominal). They are also required to be tolerant of connection to either side of the power bus and to polarity reversal.

2.4.3.5.3 Firing Circuits. Paragraph 3.2.1.3 of the CREST Specification requires firing circuits to include electrostatic protection and isolation. The electronic components and subsystems are required to be connected into an integrated network by a signal transmission system.

2.4.3.5.4 Reliability. Paragraph 3.2.3.3 of the CREST Specification requires trade studies to increase signal transmission reliability through reduction in the number of connections, contacts, junctions, etc.

2.4.3.5.5 Electromagnetic Radiation. Paragraph 3.3.2 of the CREST Specification specifies EMC, EMI and transient impulse susceptibility requirements.

2.4.3.6 Propulsion

2.4.3.6.1 Catapult. Paragraphs 3.1.7.2 and 3.7.1.6.2 of the CREST Specification require the catapult to be capable of variable thrust levels in order to adjust the loads imparted to the ejectee in accordance with the maximum allowed for the particular risk assessment. Table 3 of the specifications gives the Dynamic Response limit values for the catapult. With a controllable variable thrust catapult, the system should be capable of ejecting the seat and occupant when experiencing the maximum in-flight accelerations. This would require satisfactory catapult performance under loads as high as 9.0 g's in the Z-axis in order to meet the anticipated capabilities of the Air Superiority and Multi-Role Fighters. The specification, however, only requires a 5.0 g capability. Paragraph 3.1.1.4 of the CREST Specification describes the catapult as a "dual catapult assembly" and paragraph 3.2.2.3.1.c limits the maximum catapult load factor to 22.8 G's.

2.4.3.6.1.1 Catapult Thrust Angle. The angle between the seat back tangent line and the catapult thrust line should not be such as to cause the thrust of the catapult to pull the ejectee away from the seat back, but rather should be such as to cause the thrust of the catapult to push the ejectee backward into the seat back. This requires the catapult thrust line to be parallel to the seat back tangent line or to have an angle which is more forward than that of the seat back tangent line.

2.4.3.6.2 Rockets. Paragraphs 3.1.1.3 and 3.1.7.2 require that the thrust level of the rockets to be controllable. Paragraph 3.1.7.2 further requires that direction of the thrust vector be variable for trajectory, attitude and stability control. Empennage clearance and attitude control are important tasks for the thrust vector control (TVC) concept, but if open ejection seats are to be used successfully in ejections where the seat and occupant are exposed to dynamic pressures of as much as 2100 PSF, TVC could be the only practical way to reduce the decelerations parallel to the relative wind to tolerable levels.

2.4.3.7 Restraint. Paragraph 3.1 of the CREST Specification defines the system as having "a body positioning and restraint method that can be repetitively operated during flight and is power-assisted and pilot-commanded with an automatic G-adaptive control option" and "a pre-ejection torso and extremity positioning method that provides acceleration and windblast protection as well as prevents contact with the cockpit and cockpit equipment". Paragraph 3.1.1 describes the restraint system as being "a seat mounted torso harness".

2.4.3.7.1 In-Flight Positioning and Restraint. There are no specific requirements for the number of cycles, length of travel, or force magnitude for various elements that the in-flight positioning and restraint system should be capable of. The acceleration levels delineated in paragraph 3.7.2.4.3 of the CREST Specification are less than required by future aircraft only in the eyeballs up requirements as discussed in paragraph 3.1.2.

2.4.3.7.2 Pre-Ejection Positioning. There are no specific limitations on the amount of displacement allowed between the seat occupant buttocks and the seating surface while exposed to the maximum eyeballs up accelerations. The allowable displacement should be determined and specified for the system to be capable of ejecting the occupant under such load conditions without imposing injurious loads to the occupant's spine.

2.4.3.7.2.1 Upper Torso. Paragraph 3.7.1.1.2 of the CREST Specification requires haulback of the upper torso within 0.15 seconds after ejection initiation with a maximum shoulder strap extension of 1.5 feet. The strap force is limited to a maximum of 520 pounds. It is implied that these limits are required under -3.5 Gx (eyeballs out). A fully equipped 95th percentile male produces a shoulder restraint strap load in excess of 80 pounds under a one G eyeballs out acceleration. Therefore the strap load limit leaves an excess of 520-(3.5 X 80) or 240 pounds to accelerate the upper torso aftward. Even if the maximum allowable force (520 pounds) is applied instantaneously and held constant, the time required to move 80 pounds 1.5 feet under 3.5 opposing G's would be [(2 X 1.5 X 80)/(240 X 32.2)]^0.5 or 176 milliseconds. A table of specified maximum retraction times for different opposing G values should be specified. If the 520 pounds is the physiological limit and one-half the excess strap load is the average accelerating force, a table of attainable haulback times for -Gx values would be approximately as follows:

-Gx	3.5	3.0	2.0	1.0	0
T_{max} (seconds)	.249	.231	.203	.184	.169

The shoulder restraint strap load shall not produce any downward loading on the shoulder of a 99th percentile male pilot after the pilot has been fully retracted and the catapult thrust has begun to accelerate the seat upward out of the cockpit even if the seat has been adjusted upward from its full down position. Careful consideration must be given to the specification of the minimum height of the restraint strap location above the seat reference point to meet this requirement. During the catapult stroke a positive upward Z-axis acceleration of 12 or more g's on the heaviest ejectee should exist and a downward slump of the shoulder will occur. As this slump should exceed one and one half inches for a DRI of 12. The slump is computed by the equation (slump or delta = DRI/86.9 feet). Any compression of the spine by the shoulder restraint strap less than this amount might actually be beneficial in reducing the overshoot in the compression of the spine.

2.4.3.7.2.2 Lower Torso. Paragraph 3.7.1.1.2 of the CREST Specification requires pre-ejection positioning of the pelvis but there are no distance or time requirements specified.

2.4.3.7.3 Windblast Protection. Paragraph 3.1.1 of the CREST Specification describes the system as having "Flow stagnation fence to reduce windblast induced loads on the head, torso and upper arms. Nets to prevent arm flail. Straps over the legs to prevent leg flail. Deployable panels to prevent foot rotation". Paragraph 3.7.1.3.1 limits the torsion applied to the knee joint to 30 ft-lbs and paragraph 3.7.1.3.2 limits the neck loads to 300 pounds tension and 50 pounds shear.

2.4.3.8 Stability

2.4.3.8.1 Stabilization Devices. Paragraph 3.1.4.1.7 of the CREST Specification describes trajectory and stability control being accomplished "by coordinated operation of the propulsion subsystem sensors, controller/sequencer hardware and software, and aerodynamic devices".

2.4.3.8.2 Angular Limits. Paragraph 3.7.1.7 of the CREST Specification limits rotary oscillations in the x-z (pitch) and x-y (yaw) planes to +/- 5 degrees as a goal and +/-10 degrees as a requirement.

2.4.3.9 Parachute System

2.4.3.9.1 Drogue Parachute. Paragraph 3.2.2.3.1.d of the CREST Specification limits the maximum load applied by the "drogue device" to 4,000 pounds. This is unduly restrictive on design concepts wherein the drogue device is used to increase the effective drag area significantly when warranted by the magnitude of the dynamic pressure. Maximum utilization of a drogue device is an extremely practical way of minimizing the time required to decelerate to the velocity required for safe recovery parachute deployment. In a high speed ejection, this "time to decelerate" is the major portion of the total recovery time.

2.4.3.9.2 Deployment. Paragraph 3.7.1.11.1 of the CREST Specification requires the parachute to be forcefully deployed downstream within a 20 degree cone angle. Deployment time is limited to a maximum of 0.5 seconds regardless of airspeed. These are extremely important requirements and should be strictly adhered to. Past systems which have deployed the recovery parachute with a significant cross-stream vector have demonstrated unpredictable (non-repeatable) performance.

2.4.3.9.3 Inflation. Paragraph 3.7.1.11.2 of the CREST Specification limits the parachute loads applied to the ejectee to no more than those of the ACES II parachute. This is not a clear definition of the load limitations and, depending on the interpretation of test data, potentially contradictory to the limits specified in Table 4 of the CREST Specification. Paragraph 3.7.1.11.3 gives a goal for the nominal descent velocity of a 99th percentile aircrewman to be 18 feet per second under standard sea level conditions, but allows a maximum of 23 feet per second under "any set of extreme circumstances".

2.4.3.10 Seat/Occupant Separation. Paragraph 3.1.7.2 of the CREST Specification states that "the recovery parachute separates the crewmember from the seat". Paragraph 3.1.4.1.10 and 3.7.1.10 require that the occupant's separation from the seat be positive and that there be no seat/man/parachute interference. Using the opening forces of the recovery parachute to produce positive seat/occupant separation is a proven, reliable technique.

2.4.3.11 Survival Items. Paragraph 3.1.5.3 of the CREST Specification specifies that the weight of the survival equipment stored within the seat will vary from 0 to 40 pounds. Paragraph 3.1.7.2 states that the survival kit is deployed automatically at seat/man separation.

2.4.4 Recommended Specification Modifications. Sections 2.4.2 and 2.4.3 of this report have presented areas where the CREST Specification requirements are deficient for future aircraft escape systems or for high performance ejection seats in general. The following suggested changes to the specification are intended to make the document more definitive in the design requirements. All paragraph numbers referenced in this section of this report refer to the CREST Specification paragraph numbers.

(1) In paragraph 3.1.f change 700 to 787.

(2) In paragraph 3.1.7.1 add cycles/flight, retraction distance and force for various elements of positioning and restraint system.

(3) In paragraph 3.2.1.1.1 change 700 to 787.

(4) Revise figure 4 to be compatible with (3) above.

(5) In paragraph 3.2.1.1.3 change -5g to -9g.

(6) In Table 4, next to last column, change S_Z to S_X.

(7) Include a figure giving the overall envelope requirements and reference in paragraph 3.2.2.

(8) In paragraph 3.2.2.3 add the actual crash load requirements.

(9) Eliminate requirement d (4,000 lb drogue load) from paragraph 3.2.2.3.1.

(10) In paragraph 3.2.2.3.1 change 1,660 to 2,100.

(11) In paragraph 3.2.7.1 change 700 to 787.

(12) Revise paragraph 3.7.1.1.1 to require or permit an automatic ejection initiation system.

(13) Revise paragraph 3.7.1.1.2 to make maximum strap force, accelerations and haulback times compatible.

(14) In paragraph 3.7.1.1.2 change -4 G_Z to -5 G_Z.

(15) In paragraph 3.7.1.3 change 700 to 787.

(16) In paragraph 3.7.1.7.2 change 700 to 787.

(17) Add a figure (graph) or table to define maximum parachute loads and reference in paragraph 3.7.11.2.

(18) In paragraph 3.7.2.4.3 change +4g to +5g.

2.4.5 Third Generation Ejection Seat Upgrades. Preparation of the fourth generation ejection seat specification, request for quotation cycle, design, development and qualification of the system will undoubtedly span several years. Upgrading one of the third generation seats as an interim method of extending the performance envelope could be considered. Some efforts have been made in the past to upgrade all three of the systems analyzed in Task 1 of this program. These efforts are summarized in the following paragraphs.

2.4.5.1 ACES II. Three tests were conducted with modified ACES II ejection seats wherein the seats were ejected from a sled traveling at approximately 700 KEAS. Two major modifications were tested. The drogue deployment slug and extraction chute were removed and the drogue was deployed by being projected in a metal container in an upward direction, parallel to the catapult thrust line. The other modification consisted of adding a gyroscopic control to the sustainer rocket motor which was mounted in a manner which allowed it to swivel about its primary axis. This latter modification has been designated as YAWPAC by the manufacturer (Douglas Aircraft Co.). The Advanced Recovery Sequencer (ARS) is intended to be a part of the ACES II UPGRADE, but was not used in these tests.

2.4.5.2 NACES. The NACES Pre-Planned Product Improvement (P^3I) program will focus on subsystem technologies involving an improved electronic sequencer, improved occupant restraint harness, high speed envelope expansion, controllable thrust catapult, advanced signal transmission subsystem and improved recovery subsystem.

2.4.5.3 S4S. A test was conducted with a modified S4S ejection seat that was ejected from a sled traveling at an airspeed of approximately 725 KEAS. The modification to the ejection seat system consisted of adding a reefing line and two reefing line cutters to the drogue parachute system. The reefing line was configured to keep the drogue mouth completely closed until one or both of the cutters operated. The cutters were powered by pyrotechnic delays with a nominal time delay of 0.40 seconds.

The delay cartridges were fired at drogue line stretch.

2.4.6 Supportability, Reliability, and Safety Analysis. The requirements for supportability, reliability and safety are not unique to escape systems for future aircraft, but are generally the same as those required for any weapon system.

2.4.6.1 Supportability. The various requirements included in the CREST Specification to assure that fourth generation escape systems are easily maintained and require a minimum of inspections and/or replacements are summarized below. The referenced paragraphs are included in parenthesis after each requirement.

(1) Service life to be 20 years (3.2.3.2).

(2) Replacement of recovery, ballistic and propulsion subsystem components not more than once during service life of the system (3.2.3.2).

(3) The number of timed removal items to be kept to a minimum (3.2.3.4).

(4) Maintenance man-hours per flight hour to be 0.06 (3.2.4).

(5) The mean time to repair shall not exceed one hour (3.2.4).

(6) Timed removal, scheduled maintenance or scheduled inspection items shall not require more than 15 minutes to remove and replace with the seat installed (3.2.4.a).

(7) Oxygen supply shall be capable of being serviced and replaced while the seat is installed in the aircraft (3.2.4.a).

(8) Oxygen supply shall include a readily visible emergency oxygen quantity indicator (3.2.4.a).

(9) Escape system maintenance shall not require removal of any major component such as the aircraft canopy (3.2.4.b).

(10) Frequency of escape system removal from the aircraft shall be minimized (3.2.4.b).

(11) "Testability" design techniques such as Built-in Test (BIT) and self-test are required (3.5.1.1).

Item (6) implies that all such items must be removable and replaceable with the ejection seat installed in the aircraft. This is a sound goal, but cannot always be accomplished in a practical manner. When a maintenance task requires that the seat be removed from the aircraft, whether or not the removal of major components such as the aircraft canopy are required is beyond the control of the ejection seat designer. Therefore, item (9) is overly stringent.

2.4.6.2 Reliability. Paragraph 3.2.3 of the CREST Specification requires a probability of success of 0.98 at the 90% lower confidence limit to be documented through analysis using Failure Modes, Effects and Criticality Analysis (FMECA) and a mathematical model. Critical components and systems are required to be operated below their maximum capacity (derated) to ensure reliable performance. These requirements are essentially the same as those which are in the Air Force ejection seat specification (MIL-S-9479B), and which were followed during the development of the third generation ejection seats. The increased complexity of fourth generation seats, necessitated by the sensors, stability and trajectory control devices, etc. will create a much more complex mathematical model than that of the third generation seats which, in turn, will require greater component reliability in order to achieve the desired overall system reliability

Paragraph 3.2.5 of the CREST Specification requires that the system remain operational in the event

of a complete failure of the control system in that the system will revert to a set of basic pre-established performance capabilities similar to current ejection seat (ACES II) capabilities. This capability only improves the reliability in ejections which take place under circumstances where third generation type of performance would be successful, but not under all of the requirements for the fourth generation ejection seat.

2.4.6.3 Safety Analysis. Paragraph 3.3.6 requires fail-safe features to ensure against hazardous failures and that the fail-safe operation avoid the maximum (high-risk) performance and, instead, revert to nominal performance. Redundant components or systems are required where fail-safe operations are not possible or where reverting to them would produce hazardous situations. A safety device is required to be integrated into the ejection control mechanism and an additional ground safety means is required for the ejection controls. It should be stressed that single point failures are not allowed except in cases where redundancy is not practical, such as the recovery parachute. The third generation designs have catastrophic single point failures which could have been eliminated by relatively simple and practical methods.

2.4.7 Seat-Mounted Microprocessor System Analysis. The seat-mounted microprocessor system capabilities are determined by the different escape system design concepts which are incorporated into the seat for the catapult, sustainer rocket, stabilization of the seat in pitch and yaw (in both low and high speed ejections), control of high speed tipoff, providing Mach number immunity in supersonic ejections, sequencing the main recovery parachute, calibration and/or characterization of the transducers used to measure pressures, angles and/or angular rates and possibly for other functions.

2.4.7.1 Simplest Fourth Generation Microprocessor. The simplest fourth generation microprocessor is that for an escape system which incorporates a self-compensating catapult (for DRI control), a sustainer rocket or rockets having a constant impulse level and a fixed nozzle angle, an automatic means to prevent (or reduce to acceptable levels) nose-up tip off at high speeds, a self-contained means for low speed pitch angle and escape trajectory control, some aerodynamic means for high speed stabilization which will provide positive pitch and yaw stability in a preferred near zero yaw, and approximately twenty-five degree nose-up pitch attitude in the high speed airstream even before the drogue parachute has been deployed or inflated. Thus the microprocessor need only program deployment of the drogue and the main recovery parachute at the proper times and be able to distinguish between a subsonic or supersonic airstream.

2.4.7.1.1 Supersonic Condition Recognition. The functions to be provided by the simplest fourth generation microprocessor are; the determination of supersonic airstream conditions, deployment of the drogue at the earliest acceptable time, and the deployment of the main recovery parachute at the earliest possible time in every ejection condition. The simplest means to determine supersonic conditions is to sense a rapidly decreasing static (or base) pressure on the seat representing an increasing altitude at the rate of 2000 feet per second or greater. So long as this decreasing static pressure is being sensed, no altitude and airspeed measurements for parachute deployment would be made. It is noted that measurement of only one parameter (the static or base pressure) is required for this determination of a supersonic airstream condition and even this measurement may be inaccurate in magnitude so long as it is decreasing at a rate corresponding to the rate at which the actual static pressure in front of the seat is decreasing.

2.4.7.1.2 Drogue Deployment. Deployment of the drogue would be delayed by a fixed time delay after catapult separation in all supersonic ejections as well as in all high subsonic speed ejections. Immediate drogue deployment at the instant of catapult separation in all other ejections could be provided.

2.4.7.1.3 Recovery Parachute Deployment. The simplest means of providing the earliest acceptable parachute deployment is to continuously measure the static (or base) pressure and the total pressure and to deploy the main recovery parachute as soon as the combination of these two measurements meet the requirements of a table stored in the memory of the microprocessor. This table

would represent the airspeed and altitude boundary of the low speed, low altitude Mode 1 with fast time delay sequencing (50 to 100 milliseconds after catapult separation). For any airspeed/altitude combination outside this Mode 1 boundary, the sequencer will wait until the airspeed and/or altitude have decreased sufficiently to reach this boundary. The sequencer would then deploy the main recovery parachute.

2.4.7.2 Most Complicated Fourth Generation Microprocessor. The most complicated fourth generation microprocessor will be programmed to control the catapult pressure for optimum DRI values, to control the thrust magnitude and thrust direction of the sustainer rockets to provide seat trajectory control (with upward seeking capability) and yaw and pitch stabilization at all ejection airspeeds, to deploy the drogue at the earliest acceptable time, to positively sense all prevailing supersonic conditions, to calibrate and characterize all of the seat mounted transducers, to evaluate the validity of data supplied by the aircraft air data computer, to correct for nose up tip off rates in high airspeed ejections and to provide an accurate computed time delay for main recovery parachute deployment for any combination of airspeed and altitude at the time of ejection.

2.4.7.2.1 Response Requirements. The functions that must be provided by the most complicated fourth generation microprocessor include at least those functions listed in 2.4.7.2 and possibly others. Although many of these same functions are provided by the aircraft flight controller to the aircraft control mechanisms, it is believed that providing these functions to an ejection seat may extend beyond the existing state-of-art microprocessor technology. This is especially true when the practical volume limitations of the ejection seat are taken into account. The basis for this belief is the fact that the rotational rates, acceleration levels and system time constants for an ejection seat appear to be an order of magnitude faster than those of even the fourth generation aircraft. For upward seeking to be of value in an ejection in the 180 degree inverted attitude, low altitude condition, the seat must be rotated through 180 degrees in a period of less than 0.2 seconds. This requires an average rate of rotation of over 900 degrees per second, which indicates a maximum rotation rate of as much as 1800 degrees per second. Nose-up pitch rates from 300 to 450 degrees per second and yaw rates up to 300 degrees per second have been recorded in system tests at 600 KEAS. All these angular rates appear to be well above those possible in modern aircraft.

2.4.7.2.2 Catapult Control. For control of the catapult thrust the microprocessor must open and then close up to four pressure relief valves. The valve openings/closings must be based on a computed maximum DRI level for the accelerations being measured on the seat during the catapult stroke. The valve opening is not a single point failure since a second valve can be opened in the event of such failure. Valve closing, however, is a single point failure since it will result in destruction of any subsequent catapult thrust control. The use of three accelerometers with majority voting is a way to eliminate single point failures in the acceleration measurements, but even with this capability accurate measurement of the seat acceleration during the catapult stroke is considered to be a high risk area.

2.4.7.2.3 Rocket Control. The rocket(s) can perform control functions by varying the magnitude of the thrust and/or the thrust angle.

2.4.7.2.3.1 Thrust Magnitude. For control of the seat attitude by means of sustainer rocket thrust magnitude control, other devices must be added to the subsystem. For example, if thrust magnitude control is accomplished by using gelled propellants, two valves (one for the oxidizer and one for the fuel) for each of a minimum of four nozzles must be opened and closed in correct timing by the microprocessor and each of these eight or more valves represents a single failure point. The input data required for optimum seat attitude control includes seat yaw and pitch angles and angular rates relative to the high speed airstream, seat pitch and roll angles and angular rates relative to the earth surface, seat velocity vector angle relative to the earth surface, seat trajectory distance to the earth surface, static (or base) and dynamic pressures acting on the seat and possibly other inputs such as angular and linear accelerations. Each of these inputs must have three input values with majority voting if a large number of single point failures are to be eliminated.

2.4.7.2.3.2 Nozzle Angle. For control of the seat attitude by means of sustainer rocket thrust vector control, two servo type drive mechanisms for each of at least three rocket motors must be controlled by the microprocessor and each of these six or more drive mechanisms represents a single failure point. The input data for optimum seat attitude control required for this thrust vector control is the same as that for thrust magnitude control as listed in the previous paragraph.

2.4.7.2.4 Additional Input Data. The microprocessor must be connected to the aircraft air data computer via the 1553 data bus. The microprocessor then must be capable of evaluating the validity of the data received from the aircraft air data computer at the time the ejection is initiated. Without accurate pitch and yaw angle data from the aircraft air data computer, it does not appear possible for the seat mounted angular data system to determine the seat pitch and yaw angles relative to the airstream in a high speed ejection.

2.4.7.2.5 Other Functions. This microprocessor must also provide those functions provided by the simplest fourth generation microprocessor which are: the determination of supersonic airstream conditions, the deployment of the drogue at the earliest acceptable time, and the deployment of the main recovery parachute at the earliest time in every ejection condition.

3.0 Summary, Conclusions, and Recommendations

3.1 Summary and Conclusions. The CREST Mission Area Requirements Study provided an updated look into the operating environment and associated required performance of the fourth generation ejection system. The study compiled performance data for current third generation ejection systems, and their proposed follow on improvements, for comparison to the anticipated performance of future DoD aircraft (year 2000 and beyond). The comparisons were used to identify specific areas where ejection systems had performance deficiencies relative to the anticipated performance of the future aircraft concepts. With these deficiencies outlined, ejection system design performance specifications including the CREST Systems Specification for fourth generation ejection seat development were reviewed, and specific change recommendations were made to ensure that fourth generation seat concepts incorporate the performance goals necessary to meet future DoD aircraft capabilities, and improve ejection survivability.

Four specific tasks were completed in the technical approach. Task 1 - Third Generation Escape System Performance Comparative Analysis - was used to compile and compare performance capabilities of current third generation ejection seat systems. Task 2 - Performance Requirements of Future DoD Aircraft by Mission Type - compiled data on future DoD aircraft concepts and their anticipated performance capabilities. The concepts were based on a specified set of mission applications. Task 3 - Analysis of Third Generation Escape Systems to Meet Future Aircraft Escape Requirements - used the results of Tasks 1 and 2 to compare third generation seat performance to the predicted performance of the future aircraft concepts. This comparison identified performance deficiencies in the third generation seat systems. Finally, Task 4 - Analysis and Recommendations for Fourth Generation Escape System Performance Requirements - was used to review results from Tasks 1 through 3, and apply findings to the CREST System Specification. This included making specific change recommendations to better ensure that fourth generation seat systems adequately meet the performance goals of future DoD aircraft. Results of the four tasks are further summarized below.

Task 1 performed a study on four third generation ejection seat configurations. These configurations were the ACES-II and unqualified ACES-II PLUS seats developed by the Douglas Aircraft Division of the McDonnell-Douglas, the NACES seat developed by the Martin-Baker Company for the U.S. Navy, and the unqualified S4S ejection seat developed by the Stencel Aero Engineering Corporation. Additional subsystem components components considered in the evaluation included: restraint harnesses and powered inertia reel devices; propulsion subsystems; pitch/yaw stabilization subsystems; altitude/airspeed sensing subsystems; post ejection sequencers, and main recovery parachute subsystems. Performance trends of these seats were compared to the Air Force's Ejection Seat General Specification MIL-S-9479B dated 1971.

Graphical comparisons were made of the total demonstrated performance of the baseline ejection seats (with the exception of the ACES II PLUS where no test data was available). These included the time required for the aerodynamic stabilization subsystems to become effective (drogue parachutes, or fins for the S4S), and the time required for the recovery parachute to reach "first full inflation" as a function of the airspeed at ejection. Comparisons of head and neck loading were also done for this effort. These comparisons showed the effect of the drogue parachute on head and neck loading before, during, and after the drogue parachute became effective for each of the three systems. The individual comparisons made in this task represent the basic conclusions for this effort. The comparison data was used in Tasks 3 and 4 as the premise for examining the effectiveness of current ejection system technology to meet anticipated user needs in future application. More detailed conclusions regarding the relative ability of each of the ejection systems, and subsystem components, to meet these needs are formulated in the respective tasks.

Task 2 included an assessment of the operational and performance capabilities of future (year 2000 and beyond) DoD aircraft. Flight envelope parameters considered critical to ejection system performance included maximum dynamic pressure, load factors, Mach numbers, altitudes, stability margins, and maximum attitude angles and rates. Some aircraft types also had unique operational requirements such as terrain following and carrier suitability. The aircraft concepts generated were based on a set of specific mission categories. These categories included trainers, close air support, air superiority, tactical and strategic bombing, special operations, and hypersonic reconnaissance and strike. The aircraft concepts identified to fit these mission categories were the Air Superiority Fighter, Multi-Role Fighter, Close Air

Support Aircraft, Attack Aircraft, JPATS Trainer, Strategic Bomber, Special Operations Transport, and Hypersonic Intercepter/Reconnaissance Aircraft.

In general, it was concluded that the flight envelopes of the different aircraft classes could be broken into three distinct groups: subsonic, supersonic and hypersonic designs. The hypersonic concepts were unique in that they added the additional factor of high temperature due to aerodynamic heating. It was found, however, that load factor envelopes of the different aircraft classes were more mission dependent than speed dependent. Terrain following operations were also found to be a function of the mission; however, the associated speed and altitude during penetration was highly dependent on the expected threats and the signature level of the aircraft. Takeoff and landing speeds did not vary significantly between the configurations with the exception of the hypersonic reconnaissance vehicle which showed markedly higher speeds during these phases. Finally, the vehicle stability margins were very configuration dependent, and are especially noteworthy for combat aircraft concepts which are moving more and more towards unstable designs for increased maneuverability.

Task 3 compared third generation escape system performance to the performance parameters generated in Task 2 for the future DoD aircraft. Three specific parameters were considered in this comparison, Mach number versus altitude, seat/man collision with the wings or empennage versus aircraft roll rate at ejection, and aircrew personal protection equipment limits versus anticipated aircraft performance. The U.S. Air Force aircraft emergency escape design guide, and the U.S. Air Force ejection seat specification, MIL-S-9479B, were used to define the design goals to be met by the third generation escape systems. The CREST System Specification was used as the existing design goal performance level for fourth generation escape systems.

It was concluded that no third generation escape system would provide safe escape at the performance levels predicted for the Attack, Air Superiority Fighter, and Multi-Role Fighter type of aircraft. Moreover, the upgrades proposed to date did not give assurance of safe escape up to the levels required by these three future aircraft. However, they did appear to provide sufficient escape performance levels for the JPATS, Special Operations, Close Air Support and Strategic Bomber future aircraft. Furthermore, after comparing the ejection limits of current aircrew personal protection equipment with the performance characteristics of the future aircraft it was demonstrated that the equipment was deficient in providing protection for safe escape throughout the entire performance envelope of the Future Air Superiority Fighter, Multi-Role Fighter and Attack Aircraft.

Task 4 compared the escape system requirements of future high performance aircraft with the capabilities of fourth generation escape systems. The future aircraft performance capabilities used were again based on the results of Task 2. The CREST System Specification and the USAF Guide Specification were used to define the design goal performance levels for the fourth generation escape systems. These documents were reviewed for adequacy in providing the necessary system requirements to ensure that fourth generation ejection systems would meet the expected performance of the future DoD aircraft studied. This review resulted in numerous recommended changes to the CREST Specifications document which serve as the general conclusions for this task.

3.2 Recommendations. The CREST Mission Area Requirements Study was successful in identifying ejection system performance improvements necessary to meet the predicted flight and mission envelope characteristics of future, year 2000 and beyond, aircraft. The current third generation systems served as a firm basis from which to baseline system performance, and confidently measure increments due to third generation seat product improvement programs, and proposed fourth generation seat concepts. The future aircraft concepts used were equally important by providing realistic performance goals from which the comparisons could be performed, and sound design specification change recommendations could be made. The effort and results of this study provide insight into the steps necessary to realize even higher crew ejection survivability for the next generation ejection system. The following paragraphs present recommendations for more immediate follow on steps necessary to continue refining the requirements for a fourth generation ejection system.

Foremost, it is recommended that a more systematic methodology be employed to establish functional requirements for the next generation escape system. This includes implementing a Quality Function Deployment (QFD) process to aid in developing, evaluating, and prioritizing escape system functions and requirements for fourth generation ejection system application. The key element of the QFD philosophy is that it emphasizes customer (user) involvement in carrying out the process. The QFD

process features: 1) the orderly transition of ideas (from requirements to functions to design characteristics to technologies); 2) the gradual buildup of the complexity of the integrated design; 3) a Ramification Analysis which insures that all relevant constraints and degrees of freedom that impinge on the design are considered, and 4) specific team and resource planning strategies.

In addition to implementing the QFD process, it is also recommended that more engineering analyses and testing be performed to formulate solutions to the more immediate problems of inherent seat instability, and human survivability in high dynamic pressure ejection environments. This includes further investigation into the driving forces imparted on the ejection system during the critical phases of the ejection sequence where seat stability is a life or death issue. These critical phases are seat separation from the aircraft forebody, transition through the forebody flow field, and initial deployment of stability devices. Understanding the relative magnitude of the effects that these driving forces have on seat stability and occupant survivability will lead to proposed solutions for the next generation of ejection systems.

Moreover, it is recommended that these proposed solutions be considered as design increments to an overall modularized seat concept. This concept would incorporate a baseline seat with some minimal performance capability, and the additional ability to be upgraded in terms of dynamic pressure, Mach, and altitude performance (high or low) by adding specific subsystem components to the baseline seat. The rationale for this concept is based on the wide spectrum of performance capabilities associated with the various future aircraft concepts. This variance in capability presents a difficult problem in formulating a sensible single set of escape system performance requirements that are responsive to all of the aircraft. Designing a system to meet all of these performance capabilities would likely exceed any reasonable cost and weight allocations, and may well not be technically achievable. Furthermore, designing several different systems to respond to future user needs will also likely exceed cost allocations. To reduce costs and still meet the spectrum of performance requirements, a common baseline ejection system should be considered for which modular components can be added as needed to meet the specific requirements of an individual aircraft or mission application. This will allow the user to focus energy and resources on one specific seat development program with a common design goal, and ensure that the survivability rate of the next generation ejection system approach 100%.

4.0 List of References

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Appendix A

Study of the Effects of a Time Delay from System Initiation to Catapult Ignition on the Time Available for Parachute Recovery

Appendix A

Study of the Effects of a Time Delay from System Initiation to Catapult Ignition on the Time Available for Parachute Recovery.

A1. Assumed Conditions.

The assumed ejection conditions were an airspeed of 200 KEAS, a zero roll angle at system initiation, a constant roll rate of 100 degrees per second, a 98th percentile male pilot, a level flight path (zero sink rate) and no active drogue for one set of curves and a very fast acting drogue for the second set of curves. The time delay from system initiation to catapult ignition was selected at 0.1 second intervals from 0.1 second up to 0.5 second. Graphs of the seat and occupant altitude as a function of time are presented in Figures A1 and A2 for the no drogue and the fast acting drogue trajectories respectively. It was decided to use the original ejection altitude for the evaluation of the time loss produced by an increased time from system initiation to catapult ignition and subsequent separation. The condition of no drogue and a constant roll rate of 150 degrees per second was also considered. The graphs of this condition for time delays of 0.1, 0.2 and 0.3 second are plotted in Figure A3.

A2. Evaluation of Results.

In Figure A1 it is seen that the ratio of time lost to the time delay for catapult ignition is 6 for the 0.1 second time interval between the 0.1 and 0.2 second delays (see example in Figure A1), is 7 for this same time interval between the 0.2 and 0.3 second delays, is 11 for this same time interval between the 0.3 and 0.4 second delays and is 13 for this same time interval between the 0.4 and 0.5 second delays. In Figure A2 it is seen that although the fast acting drogue reduces the trajectory peak altitudes and as a result reduces the time to reach the initial ejection altitude, it reduces the ratios of the time lost to the increase in the time delay to 4.5, 5.5, 6 and 7. In Figure A3 the ratios of the time lost to the increase in the time delay are 17.5 and 16 for the 0.1 second time intervals between the 0.1 and 0.2 second delays and between the 0.2 and 0.3 second delays respectively for the 150 degrees per second roll rate, no drogue ejection conditions.

The maximum roll rate of a state-of-the-art aircraft at 200 KEAS is over 180 degrees per second according to Figure A4 and is over 150 degrees per second at 100 KEAS. From this data it is concluded that any time saving in an escape system sequencing prior to catapult separation is equivalent to over ten times any time saving which is made subsequent to that time. Thus, a strong emphasis should be placed on those subsystem improvements which will reduce the time from system initiation to catapult separation.

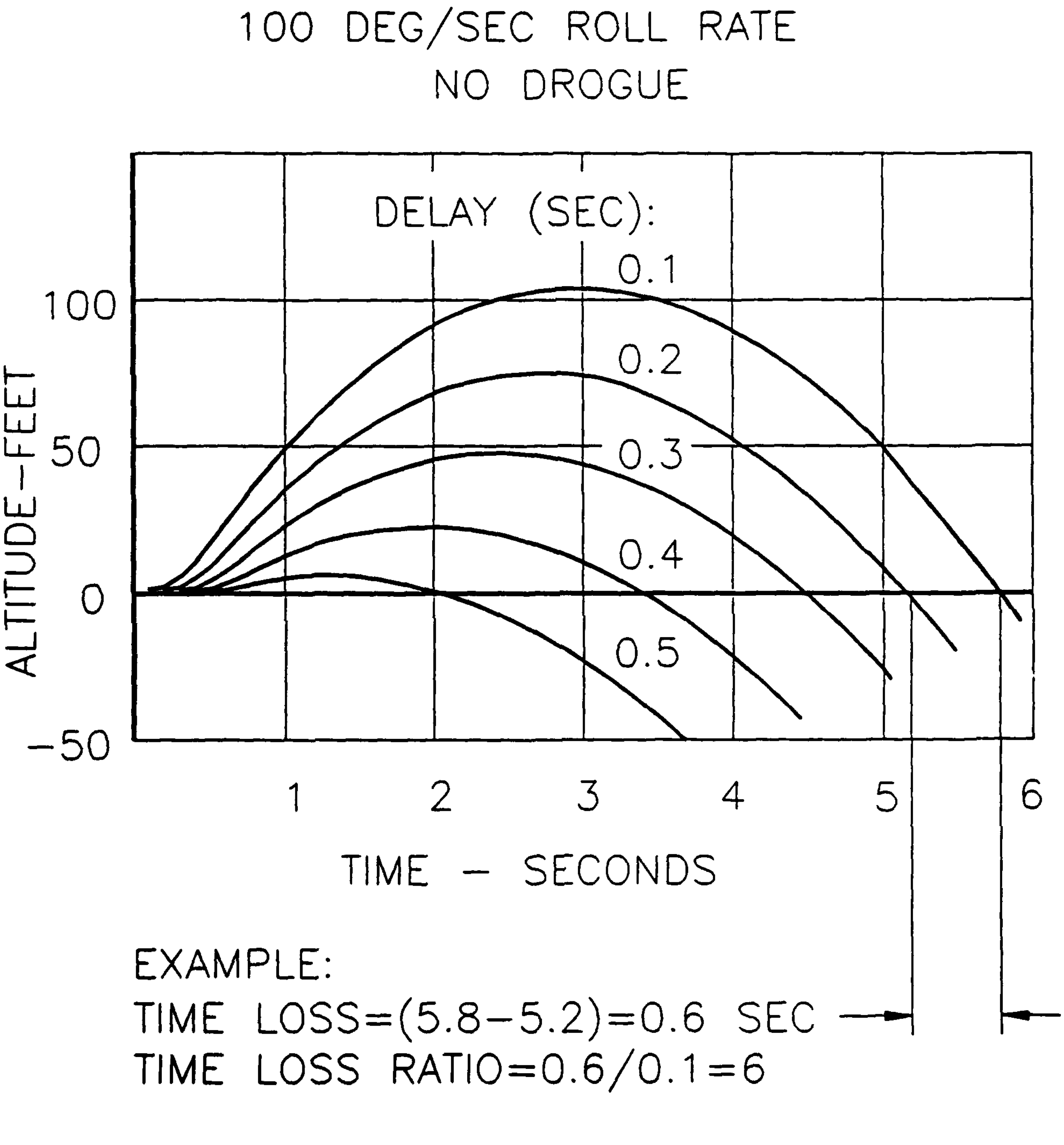

Figure A1
Plots of Altitude Versus Time for 100 Degrees Per Second Roll Rate and No Drogue.

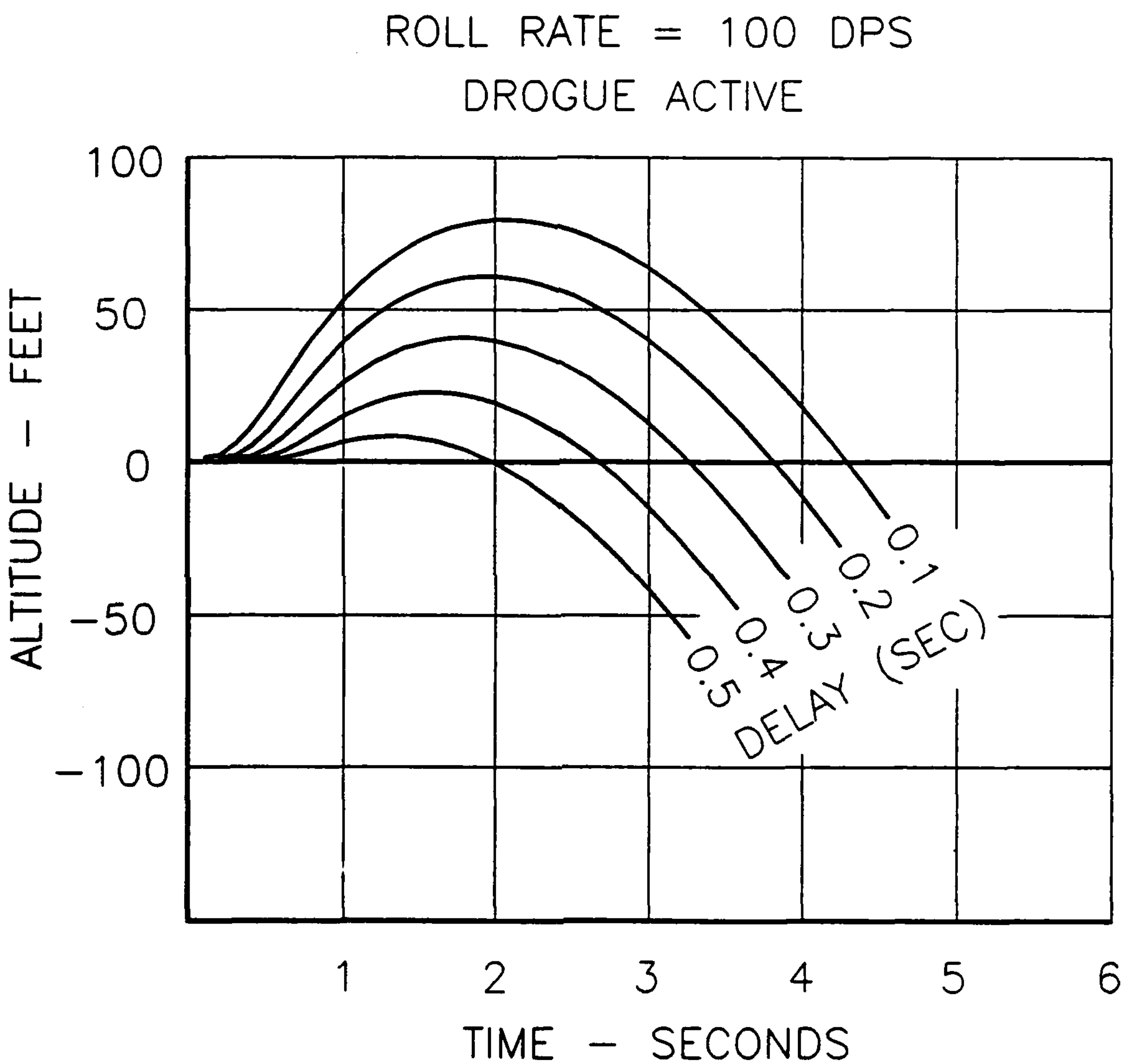

Figure A2
Plots of Altitude Versus Time for 100 Degrees Per Second Roll Rate and Fast Acting Drogue.

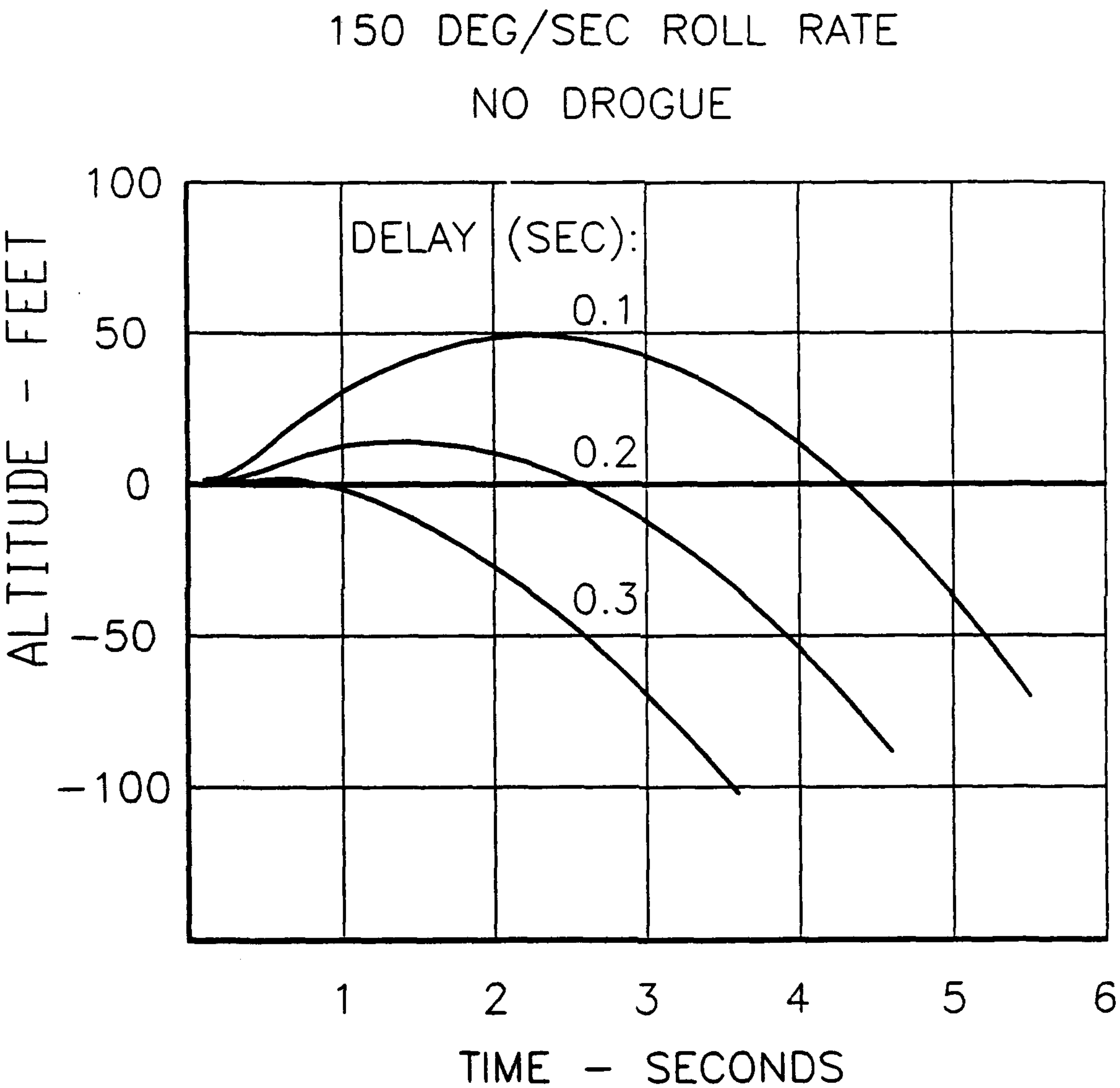

Figure A3
Plots of Altitude Versus Time for 150 Degrees Per Second Roll Rate and No Drogue.

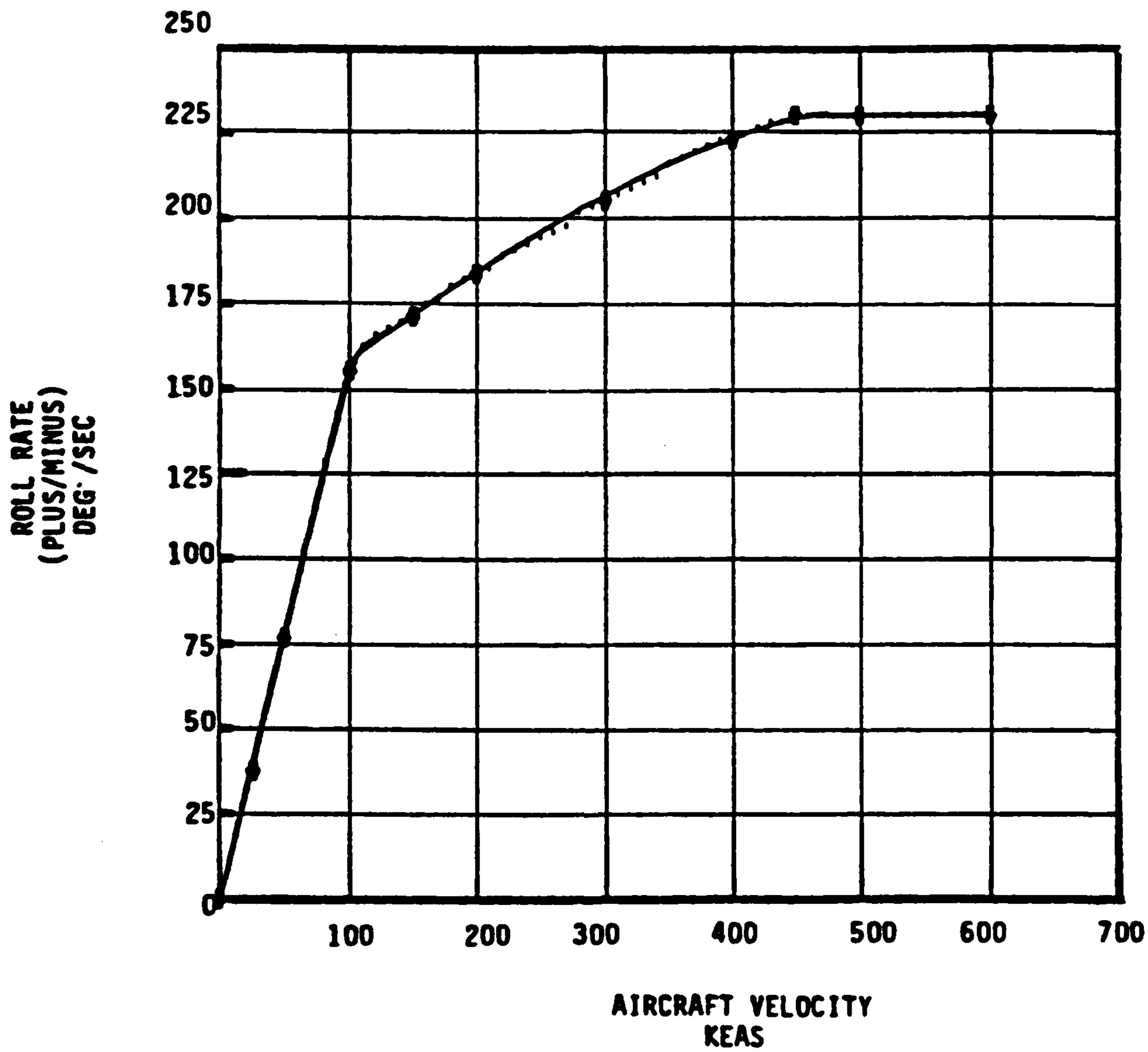

Figure A4
Plot of F/TF/A-18A Maximum Roll Rate in Flight/Ejection Envelope (Figure 3 of McDonnell Aircraft Company Document ICD-F-18-021)

Appendix B

Evaluation of the Precompression Catapult Performance Under Positive Gz Accelerations and Comparison of it and the Controllable Catapult

Appendix B

Evaluation of the Precompression Catapult Performance Under Positive Gz Accelerations and Comparison of It and the Controllable Catapult

B1. Spinal Precompression.

The Air Force has done some study of spinal precompression as a means of achieving quicker catapult separation at a higher separation velocity while staying within the DRI (Dynamic Response Index as defined by MIL-S-9479B) limits of the human body. This concept is based upon a high magnitude, short duration acceleration pulse to initiate spinal compression immediately upon catapult ignition. Ideally when the spine reaches the desired compression level (or desired DRI value) the catapult acceleration level is such that it will maintain this spinal compression throughout the remainder of the catapult stroke. Computer studies have shown that this concept may be able to provide two important capabilities to the catapult in an escape system.

The first of these two capabilities is a shorter catapult action time under normal one G escape conditions for the same maximum DRI level. The time saving in this escape condition theoretically can be as much as 0.04 seconds or more for both the 3rd and the 99th percentile male pilots. Under a low altitude, high roll rate escape condition this would be equivalent to a time saving in the recovery sequence of one-half second or more. The second capability which is provided is the major improvement which is theoretically possible in the high positive Gz ejection environment. A precompression catapult design was studied for positive Gz levels at the time of ejection of one, seven and nine. A description of the catapult design is given in B2. and the computer study results are given in B2.1. For the propellant design that had been optimized for the positive nine Gz condition, the peak DRI levels reached under the three ejection Gz levels studied were as follows:

3rd percentile - Gz = +1, +7, +9; Peak DRI = 16.7, 18.9, 20.8
99th percentile - Gz = +1, +7, +9; Peak DRI = 12.5, 17.3, 19.3

B2. Precompression Catapult Design.

The catapult design considered in this study had a larger diameter stroke for a short distance and then a smaller diameter throughout the rest of the total catapult stroke. The propellant charge was made up of three separate charges. The first charge was a fast burning pistol powder (Hercules Hi-Temp) ignited at time zero. The second charge was a standard catapult propellant (e.g., Talley Defense Systems TAL-371) of single perforation design inhibited on the outside diameter also ignited at time zero. The third charge was the same fast burning pistol powder (Hercules Hi-Temp) as the first charge but was ignited after the catapult had stroked a specified distance. Different input parameters were used in the model of the catapult on the computer to seek the lowest peak DRI level for the third percentile male pilot in the positive nine Gz ejection condition.

B2.1 Study Results.

The input parameters which resulted in the best catapult performance under positive Gz levels were as follows:

Large catapult area (dual tube units):	
diameter	1.875 inches
stroke	1.00 inch
Small catapult area (dual tube units):	
diameter	1.250 inches
stroke	37.0 inches
First (fast burning) charge:	
diameter	.0560 inch
width	.0112 inch
weight	4.80 grams

Second (slow burning) charge:

inside diameter	.4376 inch
outside diameter	.9376 inch
length	2.10 inches
weight	31.9 grams

Third (fast burning) charge:

diameter	.0560 inch
width	.0112 inch
weight	2.50 grams

Figure B1 includes the computed DRI as a function of time for the third percentile male pilot for ejections under positive Gz levels of one, seven and nine. Figure B2 includes these same curves for the ninety-ninth percentile male pilot. In these figures it can be seen that two peaks occur in the spinal compression or DRI value during the catapult stroke. The first peak occurs soon after the large diameter piston bottoms out and the net catapult thrust drops instantaneously to about one half of its previous value. The second peak occurs when the catapult separation velocity becomes great enough to cause the enclosed volume to increase so rapidly that the internal pressure drops even though the slow burning propellant grain may still be burning. Table B-I provides data on the two peak DRI values as well as the catapult separation velocity and the time of separation. The values of catapult separation velocity for these conditions are considered to be very good especially in light of the corresponding peak DRI values which are appreciably lower than would be expected.

In Figure B1 it appears clear that further optimization of the three charges is possible to lower the second peak DRI values for the 3rd percentile male pilot slightly and it would be expected that any such change would result in a lowered value of the second peak DRI of the 99th percentile male pilot also.

Table B-I. Separation Velocity, Stroke Time and Peak DRI Values for the Precompression catapult.

		Separation		Peak DRI Values			
%tile	Gz	Velocity fps	Time sec	DRI	Time sec	DRI	Time sec
3	1	50.9	0.130	16.7	0.054	13.9	0.127
3	7	44.9	0.155	17.4	0.046	18.9	0.130
3	9	42.6	0.165	18.2	0.046	20.8	0.131
99	1	45.5	0.148	12.5	0.047	12.5	0.127
99	7	40.2	0.185	14.5	0.046	17.3	0.133
99	9	37.7	0.200	15.7	0.048	19.3	0.137

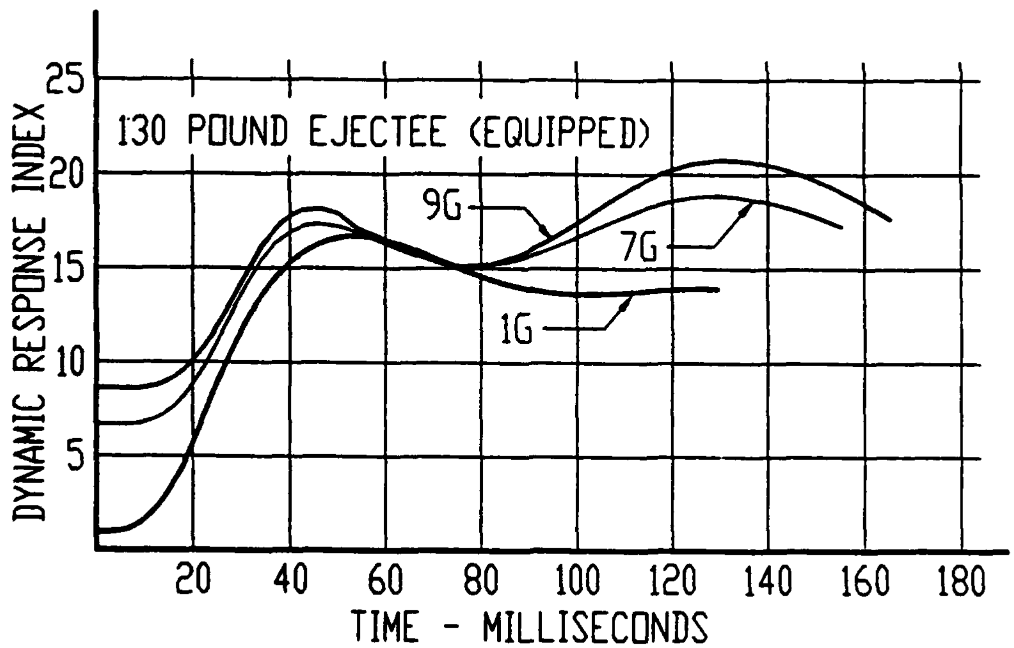

Figure B1
3rd Percentile Catapult Performance

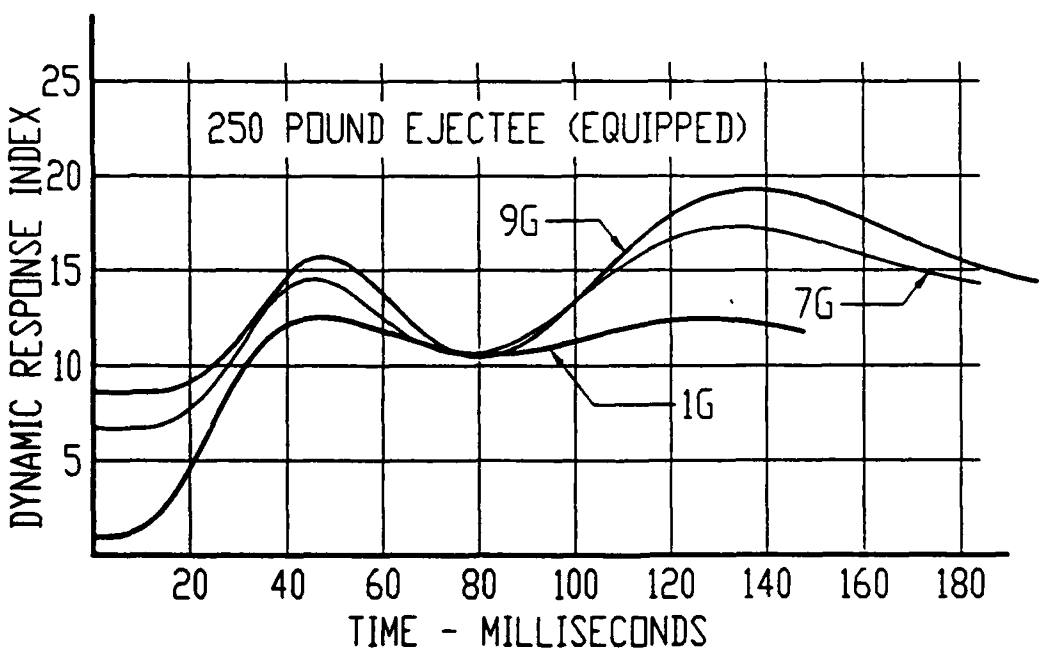

Figure B2
98th Percentile Catapult Performance

B3. Controllable Catapult.

Talley Defense Systems under Air Force sponsorship has developed the "Controllable Catapult" which can control the maximum forces applied to an ejection seat during the catapult stroke. The successful operation of this catapult is dependent upon the accurate measurement of the seat accelerations throughout the catapult action time and subsequent opening and closing of as many as four pressure relief valves. Although the design concept of this catapult is good there appear to be some considerations which give concern.

(1) The increased complexity of this unit must result in reduced reliability of the device itself. The failure of one valve to open would not be serious as other valves can back it up. However, failure of any valve to close, unless the failure occurred near the end of the stroke, could not be overcome.

(2) Experience with carefully calibrated (both before and after a test) accelerometers which are usually maintained in a tranquil environment does not give much assurance that the accelerometers which are to control the catapult pressure after several years of exposure to the severe cockpit environment will perform as required even as much as ninety percent of the time.

(3) Maintenance of tail clearance in an ejection under positive Gz may not be possible if the separation velocity of the seat away from the aircraft is cut appreciably by reducing the catapult pressure.

(4) The force-time history of the controllable catapult under a positive Gz acceleration will either result in an overshoot of the spinal DRI beyond the seat's acceleration level or the seat's acceleration rise rate will be slowed and the separation velocity of seat off the catapult will be drastically reduced. In either case maintaining positive tail clearance without exceeding the DRI limits of the human body does not appear possible in a high speed and high positive Gz ejection.

Comparing the Controllable catapult to the spinal precompression catapult indicates the following:

(1) The reliability of the precompression catapult will be higher since it is completely self contained with no external controls required.

(2) For the same catapult separation velocity and stroke time the DRI level of the precompression catapult is much less.

(3) For the same DRI level the catapult separation velocity is much greater and the catapult stroke time is much less.

Appendix C

Study of the Time Savings Provided by a Sequencer Using Continuous Sensing Versus Pack Open Time Delays Computed as the Seat Exits form the Cockpit

Appendix C

Study of the Time Savings Provided by a Sequencer Using Continuous Sensing Versus Pack Open Time Delays Computed as the Seat Exits form the Cockpit

C1. Assumed Conditions.

It is assumed that every sequencing system has the requirement to provide for the safe ejection of the 98th percentile male pilot in a ninety degree dive on an average summer day at an inland base such as NWC, China Lake or Edwards Air Force Base at a pressure altitude above fourteen thousand feet. It is also assumed that the best recovery performance will be realized when the system time delays are such that the 98th percentile pilot has parachute pack open occurring at the maximum airspeed for the prevailing altitude at which safe parachute recovery is possible. Under these assumptions the shortest acceptable time delay to parachute pack open in any ejection taking place at an airspeed above the safe parachute pack open airspeed for the prevailing altitude is set by the 98th percentile pilot, 90 degree dive, hot day ejection situation where the parachute pack open delay is computed based upon the airspeed and pressure altitude measurements made on the seat at catapult separation. It should be noted that sequencing systems which have fixed time delays for a limited number of modes (say for instance: mode change-over airspeeds of 250, 375, and 500 KEAS which is one more than NACES has and is two more than ACES-II has) can only have as good a performance as this assumed time delay system when the shorter time delay (lower mode) is selected right at the cross-over airspeed.

It is also assumed that, with continuous airspeed sensing, parachute pack opening will occur as soon as the airspeed of the ejected seat and its occupant has decayed to the safe parachute pack open airspeed for the prevailing pressure altitude.

C2. Comparison of Computed Versus Continuous Sensing Time Delays.

To evaluate the effect on the pack open time delays of the three variables, (1) hot day/cold day (110°F/30°F @ sea level), (2) 98th/3rd %tile ejectees, and (3) 90° dive/level flight, computer runs were made for all six combinations of these three variables. A maximum safe parachute pack open airspeed of 250 KEAS (comparable to the ACES-II and the NACES maximum pack open airspeeds) was assumed. The seat computational parameters used were based upon the SIIIS-3/ER seat test results.

Table C-I lists the time delays from catapult separation until the parachute pack open airspeed of 250 KEAS was reached for ejection airspeeds of 600 KEAS and 350 KEAS at a nominal 1000 feet pressure altitude. There are some important observations which become clear from this table. Since the pack open time delay as computed for the worst case conditions of a hot day, a 90° dive and the 98th percentile would be used in all ejections occurring at the same airspeed and pressure altitude in the sensed time delay system, all the other ejection conditions pay a time penalty which can be easily determined from the computed trajectories when that sequencing system is used. However, with the continuous airspeed sensing system parachute pack opening would occur at the earliest acceptable time (which is the optimum time for maximum performance) in all of the ejection conditions. As seen in Table C-I a time delay penalty of as much as 38 to 40 percent can result for the smallest pilots when a computed time delay is used rather than continuous sensing for parachute operation and all the more average size pilots (making up the great majority of the pilot population) will also have unnecessary time delay penalties.

The following conclusions have been drawn from the data in Table C-I for the 600 KEAS ejection airspeed.

(1) A temperature variation from 110°F down to 30°F at sea level results in a time saving of 7.5 to 9 percent when continuous sensing is used.

(2) Ejectee weight between the 98th and 3rd percentiles results in a time saving in a 3rd percentile ejection of 21.3 to 22.8 percent when continuous sensing is used.

(3) Flight path variation from 90 degree dive to level flight can result in a time saving of 8.2 to 9.7 percent when continuous sensing is used.

(4) It is estimated that a 50th percentile pilot ejecting at 600 KEAS on an average day (65°F @ sea level) with a level flight path will realize a time saving of 19 percent when continuous sensing is used.

Similarly the following conclusions have been drawn for the 350 KEAS ejection airspeed.

(1) A temperature variation from 110°F down to 30°F at sea level results in a time saving of about 6 percent when continuous sensing is used.

(2) Ejectee weight variation between the 98th and 3rd percentiles results in a time saving in a 3rd percentile ejection of 21.4 to 23.0 percent when continuous sensing is used.

(3) Flight path variation from 90 degree dive to level flight can result in a time saving of 11.6 to 13 percent when continuous sensing is used.

(4) It is estimated that a 50th percentile pilot ejecting at 350 KEAS on an average day (65°F @ sea level) with a level flight path will realize a time saving of 19 percent when continuous sensing is used.

C3. Airspeed and Altitude Measurement Requirements.

The time savings calculated in AppendixA, Section A2, assumed that both the computed time delays and the continuous sensing parachute timing were based upon perfectly accurate measurements of the controlling conditions of airspeed and altitude. It should be evident that a more accurate measurement of airspeed can be made for the continuous airspeed sensing parachute timing at the single airspeed for pack opening than can be made for the for the computed time delay over the full range of airspeeds up to 600 KEAS or higher. This is true because with continuous airspeed sensing the only question to be answered is: "Are the prevailing conditions less than or equal to the maximum pack open conditions of the main recovery parachute?". With the computed time delay the questions to be answered are: "Are the prevailing conditions greater than the maximum pack open conditions of the main recovery parachute and if so exactly how much greater are they?". Therefore, the dynamic pressures to be accurately measured for setting the computed time delays are throughout the full range from parachute pack open airspeed up to 600 KEAS and extend over a dynamic pressure range that is greater than a four-to-one ratio. This requires the pressure sensing transducer to be at least four times as accurate (as a percentage of full scale) as is required for accurate measurements only at the one airspeed for parachute pack open.

C4. Airflow Disturbance in Proximity to the Aircraft.

The experience gained in the application of the ACES-II seat to the B-1 Bomber provides important insight to the problems that will be experienced when a computed time delay for parachute pack open is used. In the Technical Report AFAMRL-TR-80-140 documenting the results of wind tunnel studies on the ACES-II seat exiting from the B-1, titled Multiple Ejection Effects Analysis, the airflow disturbance over the cockpit area is shown to be greatly influenced by the forebody for a distance of eight to ten feet above the aircraft. Also in this report it is apparent that other parameters, including simultaneous side-by-side ejection and Mach number, will appreciably alter the airflow over the aircraft. Thus it appears that if computed time delays are use for parachute pack opening such wind tunnel studies would be required for each aircraft in which the ejection seat was to be used and for several Mach numbers for each of these applications. Since continuous airspeed sensing will be operating well after sustainer rocket burnout in high speed ejections, the airflow over the aircraft is of consequence only for ejections right at the pack open airspeed. The disturbed airflow has a higher velocity than the free stream so even under this ejection condition the continuous airspeed sensing system would not give pack opening until the seat was past the disturbed airflow region.

Table C-1. Optimum Pack Open Time Delay from Catapult Separation for Varied Ejection Parameters/Conditions

	600 KEAS EJECTION AIRSPEED			
	98TH PERCENTILE		3RD PERCENTILE	
	90 DEG DIVE	LEVEL FLIGHT	90 DEG DIVE	LEVEL FLIGHT
HOT DAY	1.421 SEC.	1.302 SEC. (9.1%)	1.172 SEC. (21.3%)	1.096 SEC. (29.7%)
COLD DAY	1.322 SEC. (7.5%)	1.212 SEC. (17.2%)	1.091 SEC. (30.3%)	1.026 SEC. (38.5%)
	350 KEAS EJECTION AIRSPEED			
	98TH PERCENTILE		3RD PERCENTILE	
	90 DEG DIVE	LEVEL FLIGHT	90 DEG DIVE	LEVEL FLIGHT
HOT DAY	0.891 SEC.	0.793 SEC. (12.4%)	0.729 SEC. (22.2%)	0.666 SEC. (33.8%)
COLD DAY	0.845 SEC. (5.4%)	0.752 SEC. (18.5%)	0.694 SEC. (28.4%)	0.635 SEC. (40.3%)

C5. Drogue Failure.

If for any reason the effective drag area of the drogue is reduced below its normal and expected value then the ejected seat and its occupant will not decelerate as rapidly as would normally be the case when the drogue was fully effective. Therefore if a computed time delay were used in a high speed ejection the airspeed of the ejected seat at pack opening would then probably be higher than the maximum safe parachute pack opening speed and as a result the drogue becomes a catastrophic single point failure in very high speed ejections. With continuous airspeed sensing even if a complete drogue failure occurs in a fin/wing stabilized seat the only consequence will be that the parachute pack open delay is longer because without the drogue a longer time is required to decelerate to the parachute pack open airspeed.

C6. Seat Instability.

System tests of the Stencel designed S4S ejection seat demonstrated that positive seat stability at speeds up to 600 KEAS can be achieved by the use of properly designed yaw deployable stabilizing fins. Based upon the S4S test results it can be expected that seat yaw stability will improve with increasing airspeed with properly designed yaw stabilizing fins. In lower speed ejections at or near the parachute pack open airspeed when lateral divergence of the seat is applied during sustainer rocket action time (for multiplace aircraft), large seat yaw angles could possibly develop. However, in tests of the fin stabilized S4S seat at ejection airspeeds less than the parachute pack open airspeed, the seat was stabilized in a near zero yaw attitude by the time of sustainer rocket burnout. It is expected that at higher ejection airspeeds the yaw stabilizing fins will act to stabilize the seat more effectively than was true for this low airspeed test condition. An added safety margin can easily be added to the continuous airspeed sensing sequencing system. This added safety feature would be a time delay which would be activated by the sensing of an airspeed above the parachute pack open airspeed at any time during the catapult stroke. This time delay upon its activation would disarm the continuous sensing of airspeed until after sustainer rocket burnout. No time penalty in the operation of the pack opening of the main recovery parachute because at airspeeds near the parachute pack open airspeed the sustainer rockets will accelerate the seat to a slightly higher airspeed during their action time.

C7. Conclusions.

(1) Continuous airspeed sensing provides several important performance advantages over other techniques for sequencing parachute opening.

(2) Problems associated with seat yaw angles which result from lateral divergence techniques can be overcome in the continuous airspeed sensing system.

(3) Continuous airspeed sensing automatically corrects for variations in ejectee weight, atmospheric temperatures, aircraft flight path angle and even for the effects of a drogue malfunction.

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Appendix D

Study of the Time and Altitude Savings Resulting from a Higher Main Recovery Parachute Pack Open Airspeed

Appendix D

Study of the Time and Altitude Savings Resulting from a Higher Main Recovery Parachute Pack Open Airspeed

D1. Airspeed Decay in a 600 KEAS Ejection.

The decay of the airspeed of an ejection seat from its initial velocity at ejection down to an airspeed safe for main recovery parachute pack opening is a function of the ejectee's weight and the angle of the flight path relative to earth gravity. The more severe the dive angle of the flight path up to ninety degrees, the longer the time will be which is needed for the seat and occupant to decelerate to the maximum safe airspeed for parachute operation. Figure D1 includes the airspeed versus time computed for a third generation ejection seat assuming a ninety-eighth percentile male ejectee, an airspeed of 600 KEAS, with a level flight path or a ninety degree dive flight path. The two curves in this figure indicate that the increased time delay in a ninety degree dive attitude is 0.10 second, 0.13 second and 0.26 second for maximum parachute pack open airspeeds of 325 KEAS, 300 KEAS and 250 KEAS respectively. Since the parachute maximum opening speed tests are usually performed in a near horizontal trajectory the test results are optimistic by as much as 20 KEAS and they do not give a good understanding of the altitude losses which do accrue from a longer time to decelerate to the maximum safe parachute pack open airspeed.

D2. Altitude Lost Due to Increased Time Delay to Parachute Pack Opening.

The increase in altitude loss which results from a longer time delay from ejection to parachute pack opening as computed for the 600 KEAS, ninety degree dive ejection condition is indicated in Figure D2 and Figure D3. A pack open velocity of 300 KEAS versus 250 KEAS results in an altitude saving of 266 feet for the ninety degree dive condition is noted in Figure D2. The additional travel distance was computed by integration of the area under the airspeed decay curve (in feet per second) from 1.44 second to 1.97 second (from the 300 KEAS pack open airspeed to the 250 KEAS pack open airspeed). In a similar manner the additional altitude loss resulting from a 250 KEAS pack open airspeed versus a 325 KEAS pack open airspeed is indicated in Figure D3 to be 345 feet.

The additional altitude loss at dive angles of thirty, forty-five, sixty and seventy-five degrees can be quickly estimated as fifty percent, seventy-one percent, eighty-seven percent and ninety seven percent of these values. Since ground impact prior to successful parachute recovery is only probable in a dive condition these numbers are really more meaningful than just successful recovery of a ninety-eighth percentile dummy in a 600 KEAS track test where the level flight condition is represented. The importance of the reduced altitude loss which can only be realized by means of a parachute having the very highest pack open airspeed capability must not be overlooked or compromised in fourth generation ejection seats as it consistently has been in the past.

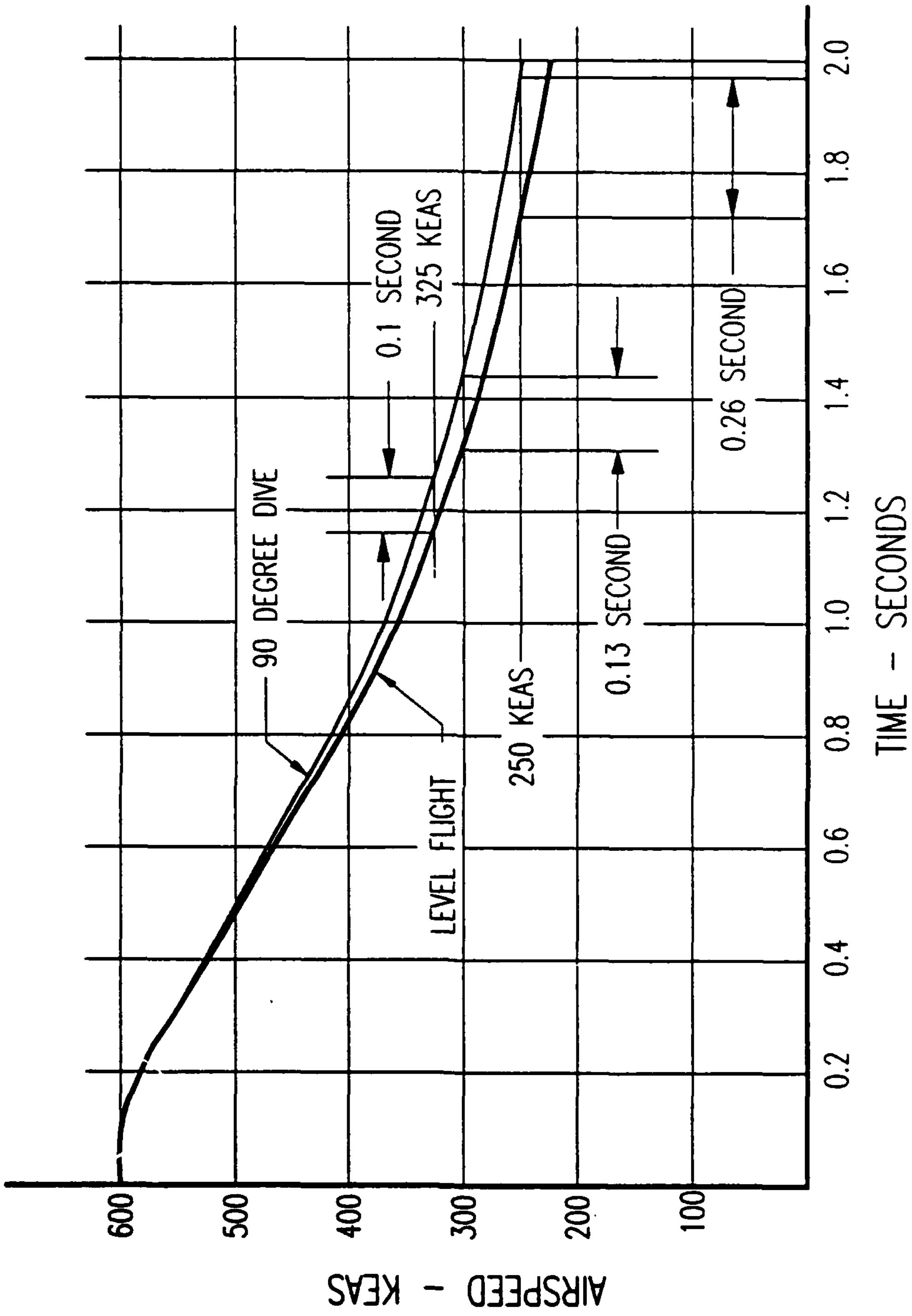

Figure D1
Airspeed Decay of 98th Percentile Pilot in a 600 KEAS Ejection

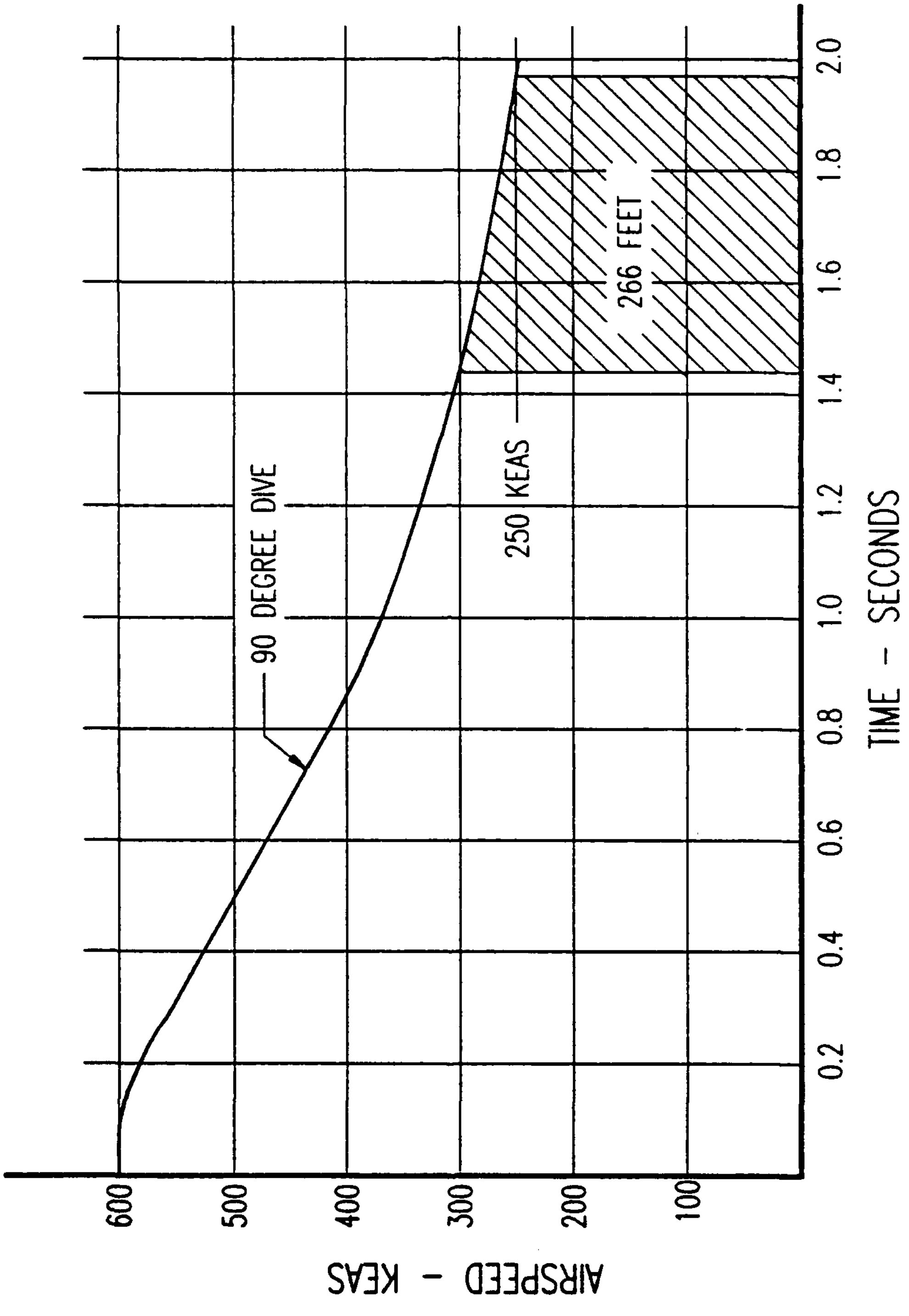

Figure D2
Trajectory Distance Saved in a 600 KEAS, 90 Degree Dive Ejection

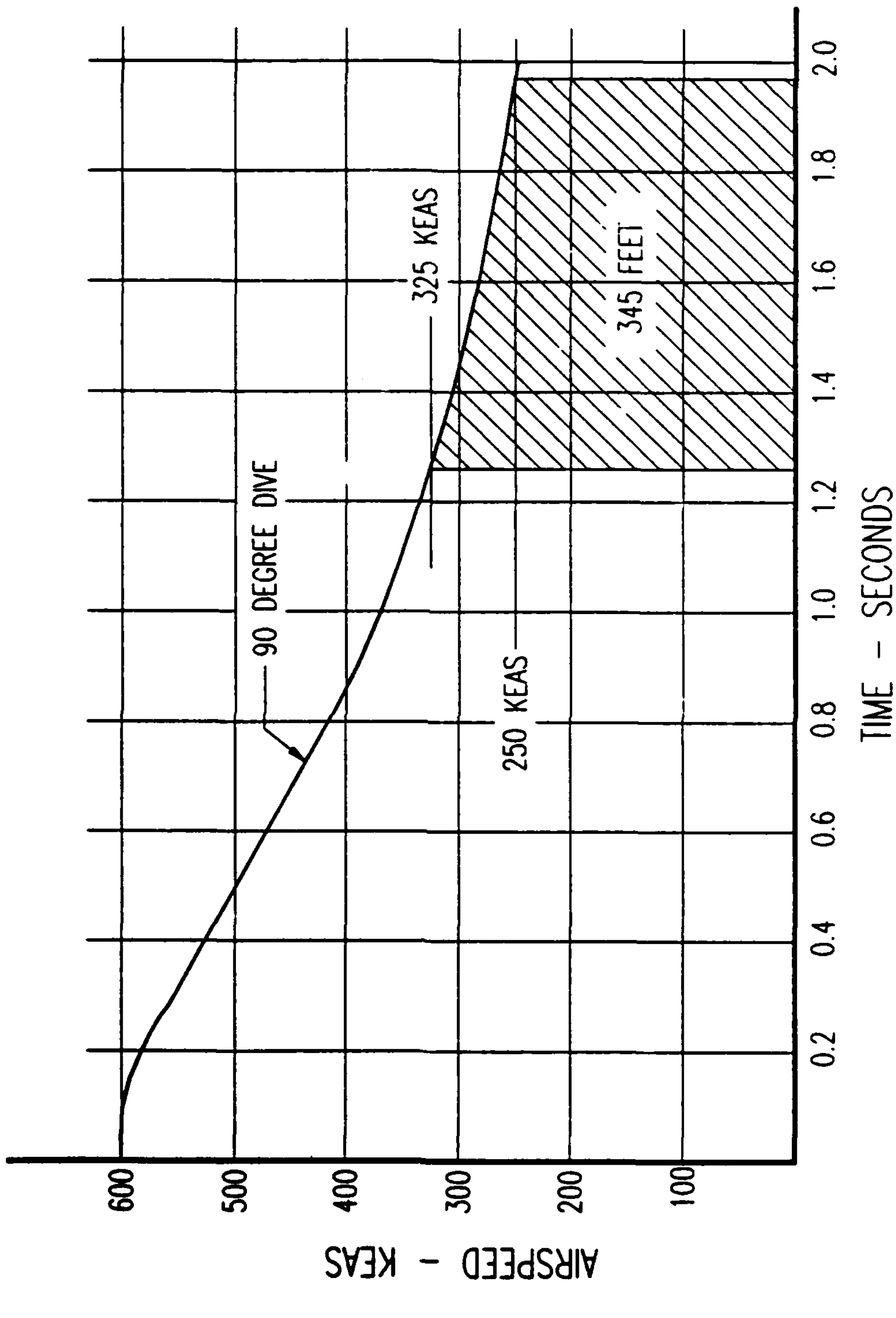

Figure D3
Trajectory Distance Saved in a 600 KEAS 90 Degree Dive Ejection

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Appendix E

Near Ground Escape System Requirements Review and Change Recommendations

Appendix E

Near Ground Escape System Requirements Review and Change Recommendations.

E1. Low Level Escape.

Low level SPEC cases influence design work at two levels. The first level is work performed by the seat designer. It is at this level that basic seat features such as rockets, control systems, parachutes, etc. are sized. The SPEC cases act as a guide during the seat sizing work. Ongoing negotiations between the seat contractor and the government determine the final result. The SPEC requirements serve the overall purpose of focusing the negotiations. The second level is work performed by the aircraft designer to integrate the seat into a given airplane. In the case of the B-1B, the ACES seat performance was degraded by forebody aerodynamic effects and by the need to employ sequence ejection. Here also ongoing negotiations between the contractor and the government determined the final result. The current low level performance SPEC should be reviewed to see if better focus could make it more useful in the overall design process.

The SPEC value is intended to represent the best seat performance available for contemporary technology. Failure to meet the SPEC value is an indication that some design feature is degrading the performance. The SPEC value acts as a focus for trade-off decisions and negotiations between the contractors and the government. Even where performance alleviation for a given design is approved, the SPEC value would still define the optimum performance possible.

The current SPEC cases are not clearly related to mission legs, but they should be. Each operational condition where the aircraft is required to be near the ground should have a requirement tailored to that leg. Each of the mission legs indicated in Figure E1 have identifiable characteristics that could be used to define a new low level SPEC requirement for that leg. Speed has a powerful influence upon the dive angle that can develop near the ground. At low speed the aircraft has more time after an emergency to push over and develop steep dive angles. At high speed the slightest push over develops a high rate of descent and large dive angles cannot develop before ground contact. This trend of large dive angles at low speed and small dive angles at high speed should be reflected in SPEC requirements tailored to mission legs. The roll angle influences performance much less than dive angle. It is recommended that the mission leg SPEC requirements be for zero roll attitude. This does not suggest that roll angle be ignored when defining the system performance for a given design. It only means that roll angle is not included in the SPEC value.

A brief examination of the conditions during each mission leg is included herein. The object is to provide just enough supporting information to explain the recommended SPEC value for each mission leg.

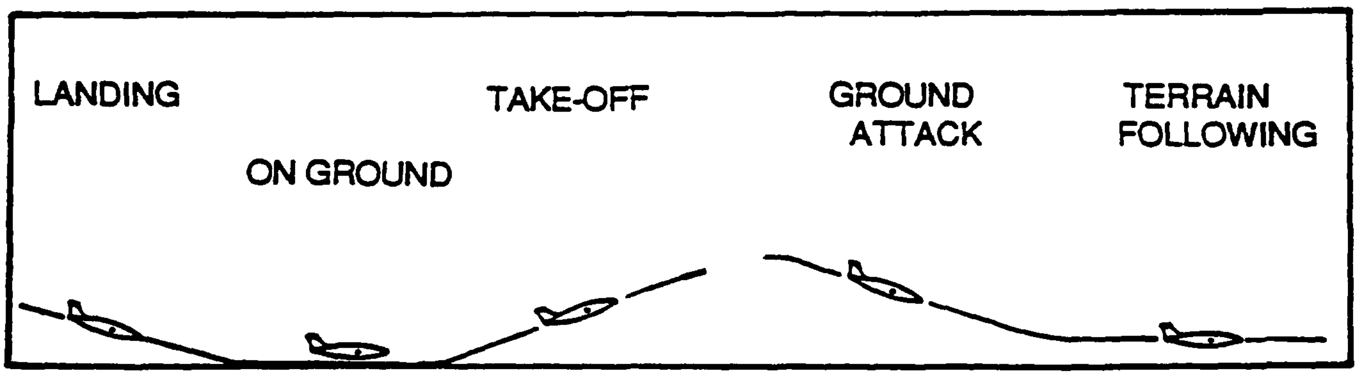

Figure E1
Low Level Mission Legs

E1.1 Landing

An emergency during final approach to landing accounts for about 30 percent of all accidents. Typical escape conditions during landing are indicated in Figure E2. A three degree glide slope at 294 feet per second (174 kts) is shown. Complete loss of power and a free fall to the ground is assumed. It can be seen that the time to ground impact and the angle of impact can vary greatly depending upon where along the glide slope the emergency occurred. Almost any roll or dive angle could be present at ejection during a landing emergency.

Figure E2 reveals a basic problem concerned with landing emergencies. The time from emergency to ground impact is very short. For example, at 15,000 feet from the runway the case shown indicates 6.5 seconds. Allowing 1.5 seconds for seat recovery, the crew member has a mere 5 seconds to decide to eject, and then to do so. Since every accident is investigated, the crew member has a tendency to wait until it is very clear that ejection is necessary. There is a tendency to eject later rather than sooner. It might be worth considering removing this decision from the crew member. A low level automatic ejection system could be developed.

A low level automatic ejection system would consist of a software program activated by inputs from the aircraft instruments. Logic could be developed based upon aircraft speed, altitude, and heading that would define limits where ground impact is unavoidable. For the pilot to remain with the aircraft below this limit would reduce chances of safe escape to no purpose. Such a system would also provide later evidence that ejection was required.

The minimum terrain clearance required for the ACES/B-1B escape system is worth reviewing at this point. The minimum terrain clearance required for wings level dives and constant altitude banked flight versus speed is shown in Figure E3. The seat trajectories for one point on the plot (60° dive, 0° roll, 200 kts) is presented in Figure E4. The point to be noted is that Figure E3 has a characteristic shape. Making a single point on Figure E3 a SPEC requirement automatically defines the entire system performance.

Returning to the landing requirement situation it is now possible to make a recommendation. A single requirement of 90 degrees dive at 200 knots would be sufficient to cover all cases. The terrain clearance required for the 90 degree dive case at 200 knots should represent the best performance of the current operational hardware. This requirement would allow everyone concerned to know at once if a given seat system is an improvement or degradation from the best capability for landing cases.

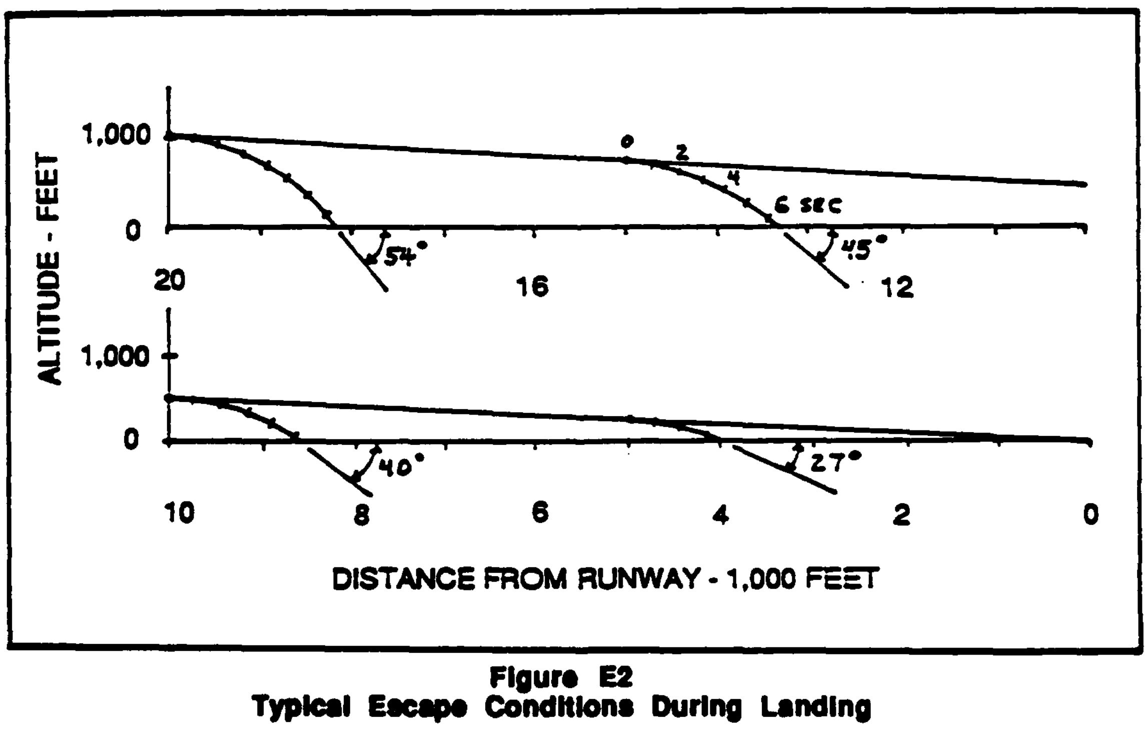

Figure E2
Typical Escape Conditions During Landing

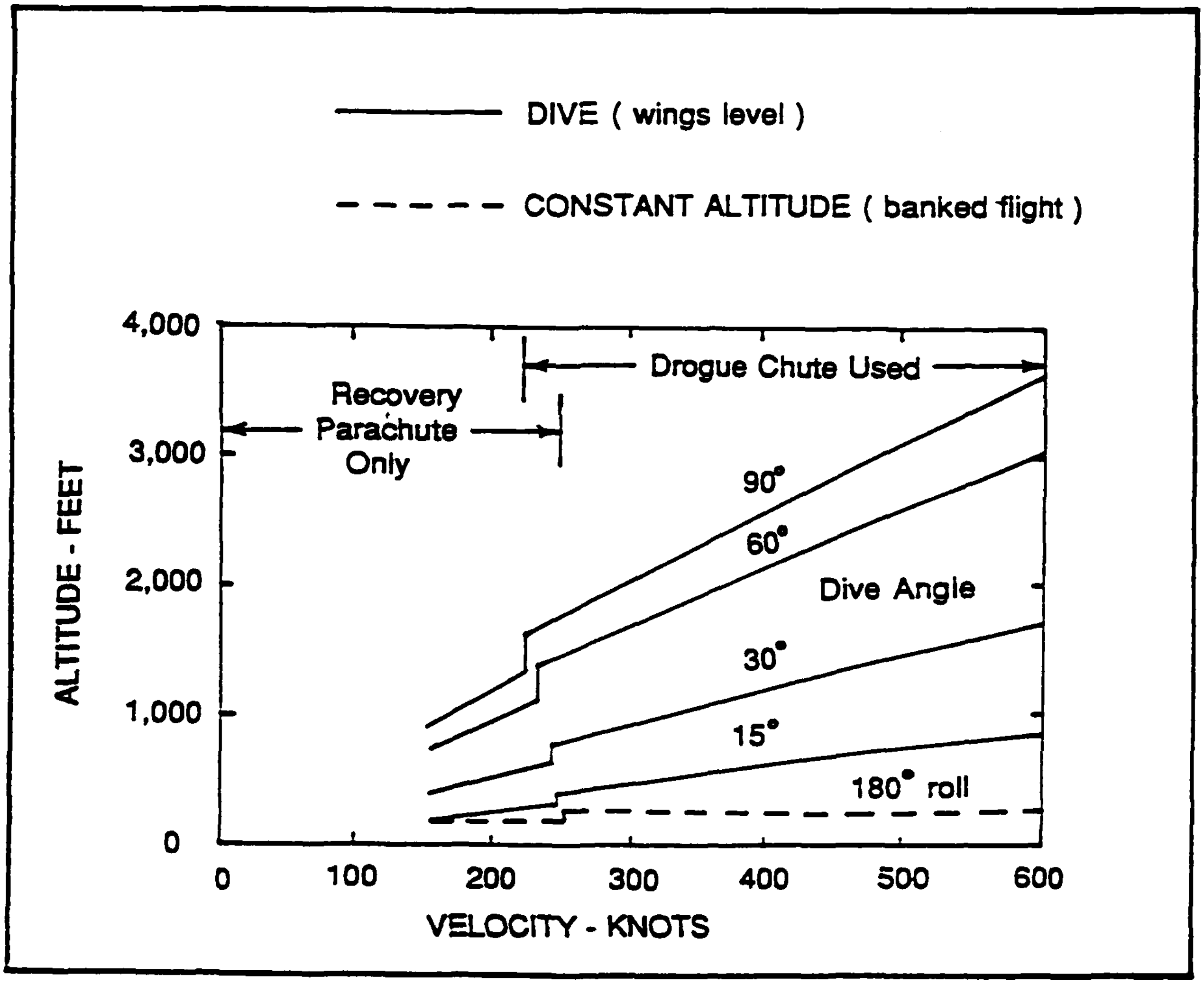

Figure E3
ACES/B-1B Minimum Terrain Clearance Required

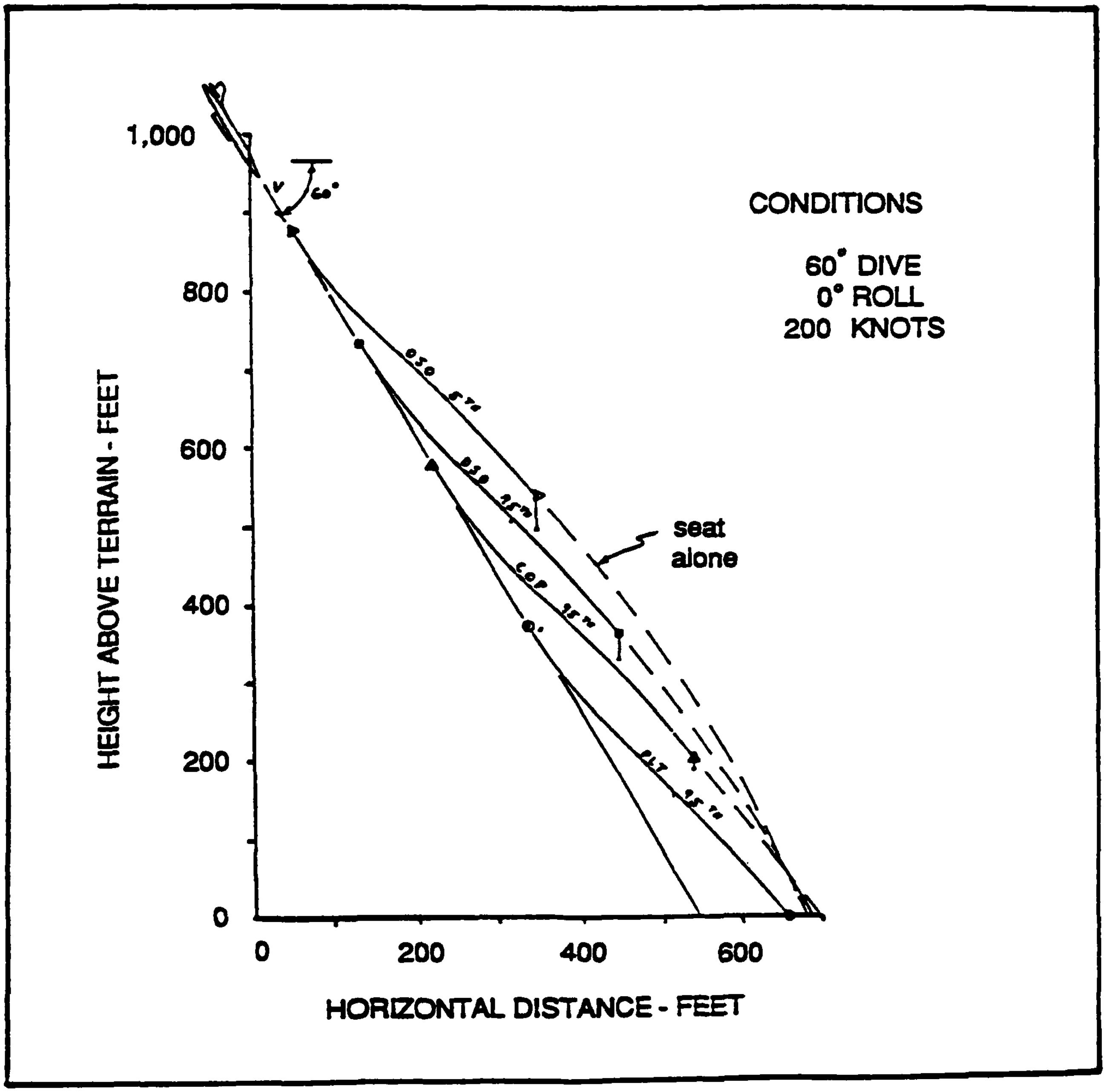

Figure E4
Typical ACES/B-1B SPEC Dive Case

E1.2 Takeoff

An emergency during takeoff accounts for about 18 percent of all accidents. The takeoff situation is basically like the landing case. The climb-out angles are a little steeper than glide slopes, the time from emergency to ground impact is a little longer, and the angle of impact is a little greater. However, the conclusion is still the same. The speed and altitude at ejection can vary over a wide range depending on where along the climb-out the emergency occurs. For the same reasons given for the landing case, a single requirement of 90 degrees dive at 200 knots would be sufficient to cover all takeoff cases.

E1.3 Ground Attack

An emergency during ground attack accounts for about 8 percent of all accidents. The ground attack mission requires the airplane to approach the target at a fairly steep angle, launch some weapon, and then perform a fly-up to avoid the ground. A typical case is shown in Figure E5. An emergency was assumed to occur at 10,000 feet from the target. In one instance the aircraft free falls to the ground, and in a second instance the aircraft performs a 3g push-over to the ground. The point at which the aircraft must start recovery is shown, and the point where the crew member must eject is indicated.

It can be seen in Figure E5 that the time available to eject is short, and the attitude conditions at ejection can vary greatly depending on where the emergency occurs. The free fall case has about 8.1 seconds to ground impact after an emergency at 10,000 feet from the target. The crew member must eject after about 6.8 seconds. Because of the high speed during ground attack the maximum dive angle at ejection will be much less than 90 degrees. The free fall case would be about 32 degrees, and the 3g push-over would be about 53 degrees. Roll attitude could be anything. There is no speed or altitude at ejection that is more meaningful than any other for ground attack emergencies.

It is recommended that a single low level requirement be adopted for evaluating the ground attack mission leg. A dive angle of 45 degrees, a roll angle of 0 degrees, and a speed of 500 knots is suggested.

Figure E5 further highlights the need to eject promptly from a stricken aircraft. Very significant improvements in seat performance might buy only one more second of delay. One or two seconds might be saved by providing the crew member with an automatic ejection system capability. Automatic ejection is a good trade-off against trying to provide a significant improvement in seat performance.

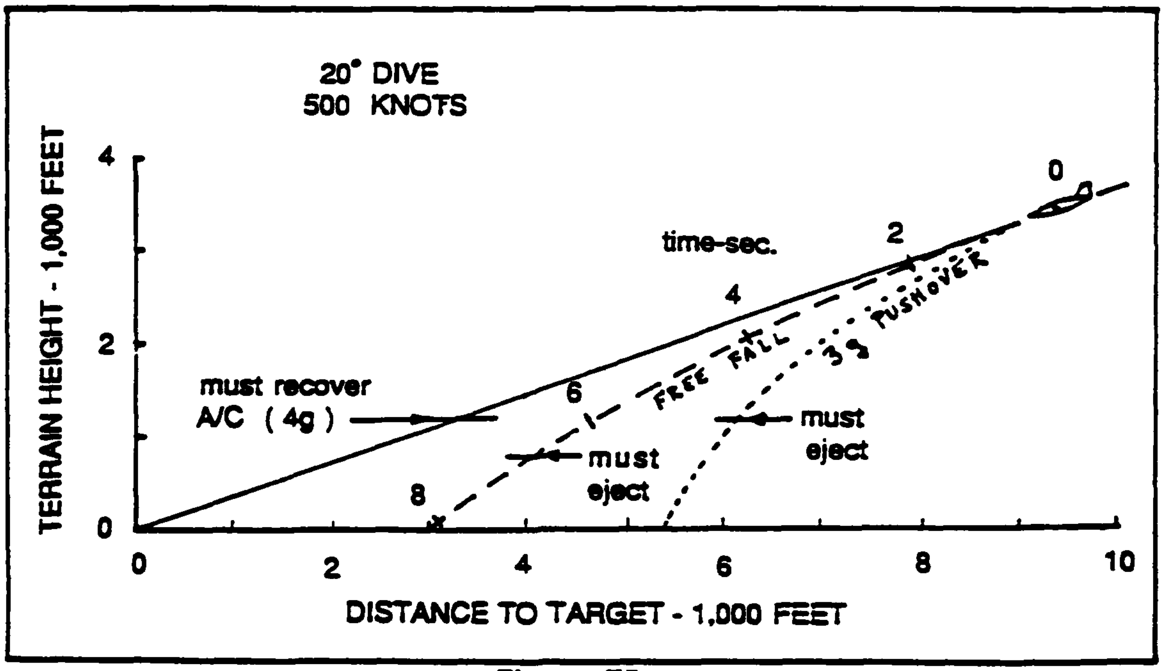

Figure E5
Typical Escape Conditions During Ground Attack

E1.4 Terrain Following

An emergency during terrain following accounts for about 6 percent of all accidents. During terrain following an emergency that causes the aircraft to push-over is a serious matter. A 2g push-over from 200 feet altitude at Mach 0.85 would hit the ground in about 2.5 seconds. This situation is indicated in Figure E6.

It can be seen in Figure E6 that the crew member would have to eject in 1.5 seconds after the emergency to avoid the ground. The assumed emergency is realistic and illustrates the hair trigger nature of an emergency during high speed terrain following.

Figure E6 also indicates that large dive angles do not develop for a high speed push-over emergency. For the case shown the dive angle would be about 6 degrees at ejection. A single requirement for terrain following is recommended. This would allow everyone to quickly determine the adequacy of a given design installation. A 5 degree dive, 0 degree roll, Mach 0.85 at sea level condition is suggested. The altitude required for this condition for a good seat system would be about 150 feet.

Even automatic ejection might not buy enough additional time to insure safe ejection during terrain following. The must-eject altitudes are just too close to the terrain following altitudes. Some seat features may be required. For instance, rockets could be used to perform a seat fly-up maneuver after ejection.

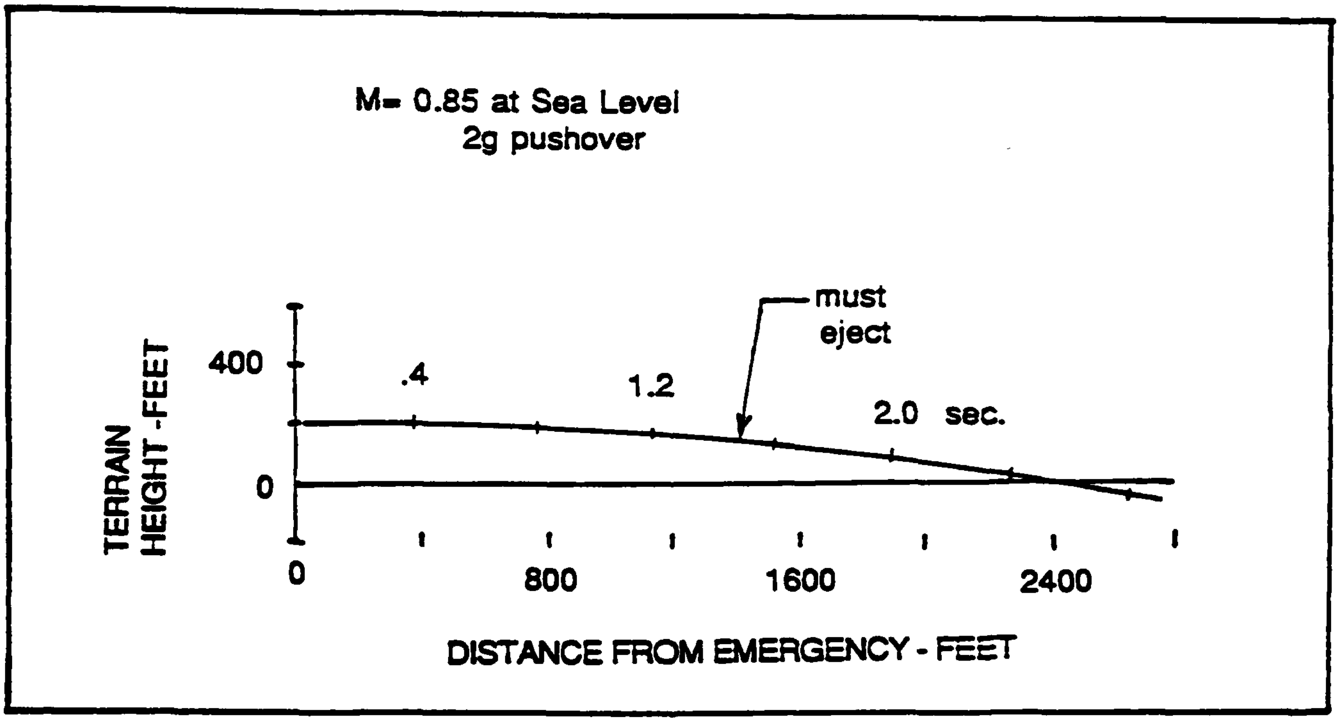

Figure E6
Typical Escape Conditions for Terrain Following

E2. Summary, Conclusions, and Recommendations

Overall, low level emergencies account for about 62 percent of all accidents. Low level flight is inherently dangerous.

The low level escape SPEC cases should be related to mission legs. A single requirement for each leg would be sufficient. Each leg requirement would be defined by the seat hardware performance, and all other conditions would be proportional to it.

In general, the time prior to ejection and the attitudes at ejection are greater at lower speeds and decrease as ejection speed increases. At high speed even small dive angles result in a high vertical rate of descent. These trends should be reflected in low level escape requirements tailored to mission legs. The following table illustrates what a new set of requirements might look like.

The problem of low level escape involves hair trigger decisions to eject. An automatic ejection system should be considered to either augment or replace the crew member's input. An automatic system would determine from aircraft instruments when ground impact is unavoidable. If the crew member has not ejected by this point the system would provide ejection actuation.

At high speed the times and altitudes are so small that automatic ejection may not help. At high speed things like providing a seat fly-up capability may be necessary to improve the crew member's chances of safe escape.

Table E-1. Recommended Near Ground Escape System Performance Requirements

MISSION LEG	ATTITUDE		VELOCITY	ALTITUDE*
	ROLL	DIVE	knots	feet
On Runway	0	0	0	0
T.O and Landing	0	90°	200	458
Ground Attack	0	45°	500	798
Terrain Following	0	5°	560	56

* Typical Only - To Be Determined

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